GE Power Management

Microprocessor Based Generator Protection Relay

MGC series 1000

Instructions

GEK 105191B

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Anything not clear enough?

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1. DESCRIPTION

The 1000 series MGC is a digital generator protection system that provides several protection functions such as: thermal protection by means of the thermal image derived from the line current (49), phase-to-phase short-circuit (51), phase-to-ground short-circuits (51G), and protection against current unbalance or reversal (46).

The relay has been implemented using digital technology and is enclosed in a 1/3 standard rack case of 19" wide by 4 units high.

The MGC has two tripping contacts, one of which is normally open and the other, electrically insulated, is normally closed. 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 contacts. It also contains a NC contact as a device alarm.

These instructions do not purport to cover all details or variations in equipment nor provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to:

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2. MODELS

Data required for completely defining a model are indicated in the following table. Please state clearly the relay's desired characteristics together with the precise type identification.

MGC	1	0	*	0	D	0	1	0	*	00	*	DESCRIPTION
			0									CT Phase= 5, CT Ground=5
			1									CT Phase= 5, CT Ground=1
			2									CT Phase= 5, CT Ground=0.02 (*)
			3									CT Phase= 1, CT Ground=1
												Auxiliary Voltage
									F			24/48 Vac/Vdc
									G			48/125 Vac/Vdc
									H			110/240 Vdc - 110/220 Vac
											C	Mounted in a drawout case
											S	Mounted in a MID system
											∅	Non-drawout case

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

3. OPERATING PRINCIPLES

3.1. MGC Configuration

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

Settings

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

0:	50 Hz
1:	60 Hz

3.2. Thermal Protection

The MGC protection system, as mentioned earlier, provides thermal protection for three-phase AC generators by means of the thermal image obtained from the line current. The MGC 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 are given in times Is (see section MGC FRONT PANEL CONTROLS for details on the Is setting),

Thermal Image Units

The thermal image unit measures the currents of the three phases. The protected circuit's line transformers supply the power for the relay input transformers, which reduce the currents to adequate levels. These currents 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:

$$I_{eq} = \sqrt{(I_1^2 + K_1 I_2^2)}$$

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

In the previous formula, the negative sequence is included for protecting the generator against the effects produced by unbalanced currents, originated from the opening of one phase, phase unbalance 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 a supplementary heating in the rotor that is transmitted to the stator, producing the effect of an overload. The MGC thermal image takes this effect into account and protects the generator against the overheating produced in the rotor and the stator due to the unbalanced currents. The thermal image unit safely protects the generator under short term large overload conditions.

The thermal image unit also protects the generator against excessively frequent pickups, given that 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 is processed by means of a thermal image algorithm to find an equivalent temperature θ at every moment. When θ reaches a limit value of θ_{lim} it causes the output to trip and the red TRIP LED illuminates

The MGC 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 generator would be stabilized applying a symmetrical three-phase current system of the same modulus as the tap current. Please see section MGC OPERATION for the description of the reading 's details.

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

The time constants can be set between 1 and 20 minutes, in 1 minute steps. Operation times for time constants greater than 1 min are obtained by multiplying t by the corresponding factor. Thus, for example, the times for τ= 6 will be six times those corresponding to $\tau = 1$.

When a stopped generator cools, the time constant that is used is different to the one that is used for a generator that cools while operating. This new time constant can be set from 1 to 6 times the operation time constant with the generator in service. For the sole purpose of selecting the time constant that is to be used, the MGC considers that the generator has come to a stop when the positive sequence component is less that 15% of the tap current.

Settings:

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

1-1 Negative sequence component overvaluing constant (K_1)
Range: 1 to 6 in steps of 1
Units: Non dimensional

1-2 Time constant (τ_1)
Range: From 1 to 20 in steps of 1.
Units: Minutes

1-3 Time constant for cooling with the generator stopped (τ_2)
Range: From 1 to 6 in steps of 1.
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 pickup 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 this unit occurs at 100% of the programmed pick-up value; it resets 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 1 to 8 in steps of 1.
Units: Times Is.

2-2. Delay.
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 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 pickup value. If it is exceeded, the negative sequence unit timer is started. When the timer reaches the programmed item, the tripping output actuates and the red TRIP LED lights up.

The pick-up of the unit occurs at 100% of the programmed pick-up value; it resets 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 currents to the left of the programmed values.

The pick-up of the unit occurs at 100% of the programmed truncating value; it resets at 90% of the programmed truncating value. The minimum tripping value is 105% of 0.1, that is, 0.105.

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: Form 0.05 to 10 in steps of 0.05
Units: seconds

3-4: Curve truncating value
Range: From 0.1 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 the wrong mode is selected in setting 3-1.

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 power supply system.

This current, after having been filtered to remove the third harmonic, 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 up.

The pick-up of the unit occurs at 100% of the programmed pick-up value. It resets at 90% of the programmed pick-up value.

Settings

The zero sequence unit has been assigned 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: Delay.
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.

POWER SUPPLY

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

4. APPLICATION

Before selecting a generator protection system, it is important to carefully consider its main characteristics such as power, operating voltage, etc.

4.1. Types of Generator Faults

The majority of generator faults are caused by failures in the stator winding insulation and to a lesser degree failures in the rotor winding insulation.

The insulation failures are generally caused by:

- Aging.
- Dirt.
- Overloads.
- Overvoltages.
- Mechanical damage produced by vibrations in the windings or the core.

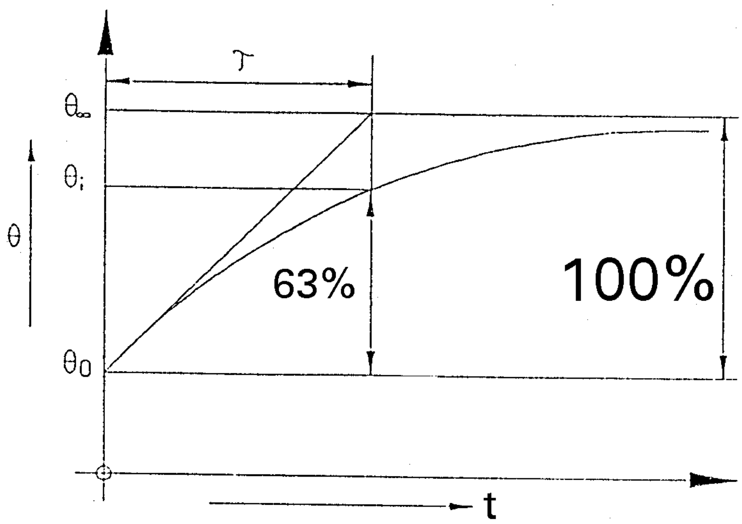
4.2. Generator in Service

According to the design and the optimization conditions, a generator 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 generator components.

In continuous duty, the generator heats up in accordance to an exponential relationship up to a final value, because heat is continuously transferred to the environment. Also, in normal operation the cooling time constants are similar to the heating time constants. On the other hand, if the generator 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 generator will take more time to cool 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 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:

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



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

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

where:

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

4.3. Generator Overload

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

- When mechanical problems make it difficult for the generator to start normally, originating a torque value greater than the rated value.
- Due to a voltage failure in a single phase.
- Due to a sudden exit from service of other generators connected to the network.

4.4. MGC Thermal Curves

The equation for the above given temperature was:

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

The MGC uses an equation in which the tripping time is a function of the generator current, thus eliminating all references to the temperatures. The time constant τ in the MGC 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 that is given by the following equation:

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

where:

t = Tripping time
τ_1 = Time constant
I = Im / Is
Im = Generator 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:

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

where:

I_e = Ime / Is
Ime = Current at which the generator 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:

$$I_m = \sqrt{(I_1^2 + K_1 I_2^2)}$$

where:

I_1: Positive sequence component
I_2: Negative sequence component

It has been found that this equation adequately represents the effect of the negative sequence component input current on the generator. The constant K_1 is and integer value programmable from 1 to 6.

These equations show the theoretical curves on which the MGC 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.

4.5. MGC System Application Range

The MGC protects the generator against:

- Overload and excessive temperatures by means of the thermal image unit.
- Phase-to-phase faults by means of the positive sequence overcurrent unit.
- Unbalanced currents, by means of the negative sequence overcurrent unit.
- Ground faults, by means of a zero sequence overcurrent trip unit.

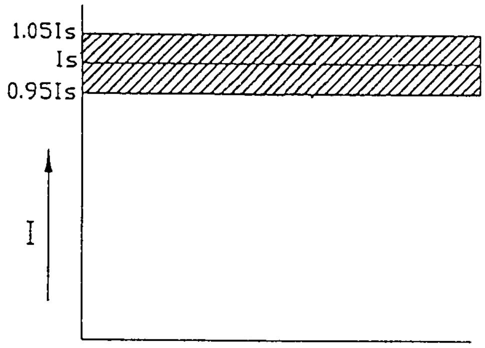
4.6. Application Criteria of the Overload Protection

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 generator 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 MGC error is ±5%, the tripping range covers from 1/0.95 Is (≈1.05Is) up to 1/1.05 Is (≈0.95 Is).

MGC TRIPPING RANGE



The main criterion that must be taken into account is: **the tripping range must be less than the generator maximum overload range.** This ensures that the relay will trip if the current exceeds the admissible overload value, thereby ensuring adequate generator protection.

The second criteria that must be kept in mind is**: the tripping range must be greater than the rated current.** This way we will optimally use the generator operation range.

If the generator characteristics are such that both criteria cannot be met at he same time, the main criteria has preference over the second one and we must resign ourselves to lose part of the operation range in order to protect the generator against insupportable overloads.

Let's look at how these criteria are applied in a concrete example:

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 = Generator rated current at full-load

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

I_N = Relay rated current.

Example:

Let us assume a generator with the following characteristics:

Power:	6000 kW
Voltage:	6000 V
Power factor:	cos φ = 0.95
Maximum permissible overload:	10%
Transformation ratio:	750/5 (150)
MGC rated current:	5A

The generator rated current is computed as follows:

$$I_M = \frac{6000}{\sqrt{3} * 0.95} * \frac{1}{6KV} \approx 607.7A$$

Now this rated current is converted to relay reading values. For this, we must take into account the line current transformer transformation ratio as well as the MGC rated current seen by the MGC, expressed in times the MGC rated current.

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

in this case:

$$I_m = \frac{607.7}{(750/5) * 5} = 0.8103$$

therefore, the maximum overload current has a value of:

$$1.10 * 0.8103 = 0.8913$$

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

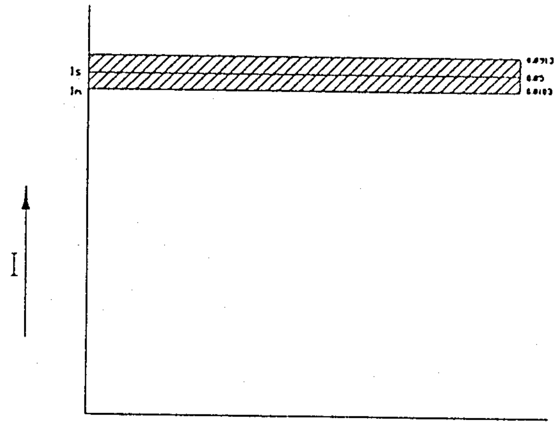
$$0.8913 / 1.05 \approx 0.85$$

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

$$0.8103 / 0.95 \approx 0.85$$

Thus, 0.85 is the value which we must select, and the trip zone will totally cover the area between the rated current and the admissible overcharge, as seen in the figure. To select this value, we must move all front panel microswitches to the left except for the ones marked 0.2 and 0.1, which gives us a sum of (0.2 + 0.1 + 0.55) = 0.85.

EXAMPLE TRIPPING RANGE



4.7 Phase-to-Phase Fault Protection

Short circuits between phases are usually accompanied by very high currents (on the order of several times the generator's rated current). Depending on the magnitude and the generator complementary protection, the positive sequence overcurrent protection function may be used as primary protection or supporting protection. If it is used as primary protection (small or insulated supply generators), the shortest possible operation time must be used. If it is used as a backup protection, it must be adequately timed so that a selective protection is provided.

4.8. Stator and Ground Fault Protection

The setting level depends on the type of generator grounding. Generally, generators have the neutral grounded through a high impedance, thus the overcurrent element must be sufficiently sensitive; it must also have a third harmonic filter, given that a generator operating under normal conditions has a third harmonic current circulating across the neutral.

An overcurrent relay such as the MIC fitted \with a third harmonic filter can also be used for this type of protection.

4.9. Unbalanced Current Protection

Unbalanced currents produce additional heating and mechanical vibration by the circulation of the induced double frequency Foucault currents in the rotor. The MGC relay has a minimum sensitivity of 0.1 x Is in the negative sequence \which is sufficient for low and medium power generators.

In conclusion, we can say that the MGC relay has been designed to offer sole basic generator protection. This relay can be used as the sole protection in low power generators (tye not to split 3 and MVA). For generators with a greater power rating, it may be complemented by other protection systems such as:

- Differential protection.
- Excitation loss protection.
- Overvoltage protection (hydraulic generators).
- Over and underfrequency protection (turbo-generator).
- Rotor ground protection.
- Power reversal protection, etc.

5. TECHNICAL SPECIFICATIONS

5.1. Current Circuits

Rated currents.

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

Thermal capacities

Continuous:	2xIn
For 3 seconds:	50xIn
For 1 second:	100xIn

Loads

For models of:

In=5A	0.3 VA
In=1A	0.3VA
In=0.02A	0.08 VA

5.2. Setting Ranges

Thermal image unit.

Tap currents (Is)

From 0.55 to 1.3xIn in 0.05xIn steps.

Time constant (τ_1)

From 1 to 20 minutes in 1 minute steps.

Cooling time constant with the generator stopped. (τ_2)

1, 2, 3, 4, 5, or 6 times τ_1

Negative sequence overvaluing constant (K_1)

Discrete values among 1, 2, 3, 4, 5 or 6

Alarm temperature

80% of the tripping temperature

Positive sequence unit

Range

From 1 to 8 times the selected tap current of the thermal image unit in 1 steps.

Operating time

Timed from 0.05 to 10s in 0.05 s steps.

Curve mode negative sequence unit

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

Zero sequence unit

Insensitivity to the third harmonic.
-20 dB

Range:
From 0.06 to 0.24 times the zero sequence unit rated current (In GRN) in 0.01 steps.

Rated current:
1A or 5A or 20 mA (optional).

Operating time
Timed from 0.05 to 10s in 0.05s steps.

5.3. Frequency

50 or 60 Hz, user programmable.

5.4. Trip Contacts

Make and Carry:	3000 W, resistive, for 0.2s with a maximum of 30A and 300 VDC.
Break:	50 W resistive, with a maximum or 2 A and 300 VDC.
Carry continuously:	5A

5.5. Alarm Contacts

Make and Carry: 5 ADC during 30 s and a maximum of 250 VDC

Break: 25W inductive, and a maximum of 250 VDC.

Carry continuously: 3A.

5.6. Accuracy

Operating value: 5%

Operating time: 5% or 25 ms (whichever is greater)

5.7. Repeatability

Operating value: 1%
Operating time:2% or 25ms (whichever is greater).

5 8. Temperature Ranges

Effective range 23° F to 104° F (-5° C to +40° C)

Operating range 14°F to 131°F(-10°C to 55°C)

Storage range -40°F to 149° F (-40° C to +65° C)

5.9. Ambient Humidity

Up to 95% without condensation.

5.10. Insulation

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

Between independent circuits: 2000 VAC during I minute at industrial frequency.

Between each output circuit terminal: 1000 VAC during I minute at industrial frequency).

5.11. Type Tests

Interference test:

2.5 kV Common mode, 1 kV differential mode, class III (IEC 255-4).

Impulse test:

5 kV peak; 1.2/50 µs, 0.5 J (IEC 255-4).

Electrostatic discharge:

Class III (IEC 801-2).

Radiointerference:

Class III (IEC 801-3).

Fast transient:

Class III (IEC 801-4).

5.12. Power Supply

There are three models (see Model List):

F Model: 24-48 VAC/VDC
G Model: 48 - 125 VAC/VDC
H Model: 110 - 240 VDC / 110-220 VAC

Consumption: less than 1.5 W at all voltages

5.13. Weights

Approximate weights:

- Net : 8.8 lbs (4 kg)
- Package: 11 lbs (5 kg)

6. CONSTRUCTION

6.1. Case

The MGC case is made of plated steel. Its dimensions are 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 scal.

6.2. Electrical and Internal Connections

Connection of the external wires is carried out at the two terminal blocks mounted on the rear panel 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 current. 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 MGC 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. MGC Front Panel Controls

The following setting and signaling elements are situated on the front panel of the MGC (as shown in figure 3):

Current tap select switch

This element selects the minimum relay operating current. It consists of 2 banks of two switches each, each 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 0.55 plus the addition of the amounts written to the right side of each closed switch.

Example: setting a relay of In=5A of an Is of 4.5A. For this purpose, and given that 5 x 0.9 = 4.5, we must close the necessary switches for obtaining an amount of 0.35, which, added to the fixed amount of 0.55, will give us 0.9; we will get this by closing the switches marked 0.2, 0.1, and 0.05 and opening the other one.

The current range is:

Is from 0.55 to 1.3 x In in 0.05 x In steps.

Push buttons and display

The MGC 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 these elements is given in the section MGC OPERATION.

6.5. External Signals

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

- READY. Green LED which indicated that the relay is in operation.
- PICK-UP. Red LED that indicates that a pick-up in one of the protection units has been produced.
- TRIP. 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 (see the section MGC OPERATION); if the relay auxiliary voltage is switched off, when it returns, the LED will retain 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 reported 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 the relay is not to be installed immediately, it is recommended to store it in its original package, and keep it in a dry and dust free place.

8. ACCEPTANCE TESTS

Upon receipt, 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 acceptance tests, at the user's discretion. Since most users apply different procedures for installation and acceptance tests, this section will indicate all tests that can be performed on the MGC.

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 MGC does not require any calibration changes.

8.1. Visual Inspection

Make sure that the model 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.

8.2. General Considerations about the Power Supply

All devices powered by alternating current are affected by the frequency. Because a non-sine wave is the result of a fundamental wave and a series of harmonics belonging to this fundamental wave, the devices that are powered by alternating current are affected by the form of the wave applied.

To correctly test relays that operate on alternating current it is necessary to use a voltage and/or current sine wave. The purity of a sine wave (absence of harmonics) cannot be expressed specifically for any given relay. However, any relay that includes tuned circuits, circuits R-L and R-C or non-linear elements (such as inverse time overcurrent relays) are affected by the non-sine waves.

These relays respond to the voltage waveform differently from the majority of alternating current voltmeters. If the AC source used for the test contains many harmonics, the voltmeter and relay readings will be different.

The relays are calibrated in the factory using a network of 50 or 60 Hz containing a minimum amount of harmonics. When testing the relay, you should use an AC source whose waveform does not contain harmonics.

The voltmeters and stop watches used to perform the trip tests and operating time tests must be calibrated and their precision should be better than that of the relay. The network power used in the tests must remain stable, mainly in the levels near the pick-up voltage.

It is important to stress that the precision used in the tests depends on the network power and the instruments used. Operating tests performed with inadequate power and instruments are useful to test that the relay operates correctly and that its characteristics are verified approximately. However, if the relay is calibrated under these conditions, its operating characteristics may be outside the tolerance levels.

8.3. Thermal Image Unit

This section describes the procedure for testing the MGC relay using three phase power supply network. The testing procedure for a single phase power supply network is described in Appendix 1.

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

2. Disable the rest of the units in order to avoid any interference when testing. To do this, zero the settings 2-1, 3-2, 3-5, 4-1 following the procedure explained in the section MGC OPERATION.

3. Set the relay tap to 1. To do this, refer to figure 3 which shows the relay front panel.

   Position all tap selection switches to the left except those marked 0.4 and 0.05; the resulting tap is (0.55 + 0.05 + 0.4) equal to 1. If you wish to perform tests at another tap, multiply the currents given in the table by the desired tap. For example, for tests at the minimum tap, multiply all of the currents by 0.55.

   $\tau 1$ set the time constant to 1 minute (setting 1-2).

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

4. Successively apply 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)	Ieq (times Is)	Operating time (s)
5	10 25 50	2 5 10	16.39-18.12 2.33-2.57 0.61-0.67

5. Repeat the test in point 4 but selecting a time constant $\tau 1$ of 20 minutes. Check that the operation time is within the ranges indicated in table 2.

TABLE 2

Rated Current (A)	Applied Current (A)	times Is	Operating time (s)
5	10 25 50	2 5 10	327.8-362.4 46.6-51.5 12.2-13.4

After each measurement the thermal image unit must be reset (please see “Zeroing the thermal image” in the MGC OPERATION section) so that the time obtained in the following test matches the values shown in figure 1 (cold generator).

8.4. Positive Sequence Unit

Connect the relay as indicated in figure 6.

Testing the pick-up

1. Set the relay tap to 1, closing the switches marked 0.4 and 0.05, and opening the rest. The positive sequence unit must be set to 1 time Is. Set the timing to 50 ms.

2. Disable the rest of the units so they do not interfere with the test, by zeroing the settings 1-2, 3-2, 3-5, and 4-1 following the procedure explained in the MGC OPERATION section.

3. Apply current to the relay and check that the PICKUP 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 greater than or equal to 85.5% of the pick-up value.

Testing operating time:

5. With the relay configured as shown in section 1, apply a current twice the value of the pick-up current (that is, 2 x Is) and check that the trip time equals 50

milliseconds within the applicable error ranges for this relay. Repeat the test with this timer set to 10s.

8.5. Negative Sequence Unit

Connect the relay as indicated in figure 6.

Instantaneous mode: testing the pick-up.

1. Set the relay tap to 1, closing the switches marked 0.4 and 0.05, and opening the rest. Select the instantaneous mode for the negative sequence unit by placing a 1 in setting 3-1. Set the pick-up value to 1 time Is. Adjust the timer to 50 ms.

2. Disable the rest of the units so they do not interfere with the test, by zeroing the settings 1-2, 3-2, 3-5, and 4-1 following the procedure explained in the MGC OPERATION section.

3. Apply current to the relay and check that the PICKUP 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 greater than or equal to 85.5% of the pick-up value.

Instantaneous mode: testing operating time:

5. With the relay configured as shown in section 1, apply a current twice the value of the pick-up current (that is, 2 x Is) and check that the trip time equals 50 milliseconds within the applicable error ranges for this relay. Repeat the test with this timer set to 10s.

Inverse time mode: testing the calibration of the pick-up taps.

6. Set the relay tap to 1, closing the switches marked 0.4 and 0.05, and opening the rest. Select the inverse time mode for the negative sequence unit by placing a 2 in setting 3-1. Set the truncating value to 1 time 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 truncating value and then the tripping relay closes.

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

Inverse time mode: testing the operating time:

9. Set the relay tap to 1. Select the inverse time mode for the negative sequence unit. Adjust the truncating value to 0.1 times Is. Select the 0.5 dial curve.

10. Disable the rest of the units so that they do not interfere with the testing, by zeroing the settings 1-2, 2-1, 3-2, and 4-1 following the procedure explained in the MGC OPERATION section.

11. Successively apply 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
(In = 5A)

Times the tap	Applied current (A)	Curve operating times (IT=0.5) in seconds
0.4	2	4.51-5.39
1.0	5	2.28-2.54
2.0	10	1.42-1.572
10.0	50	0.878-0.971

8.6. Zero Sequence Unit

Connect the relay as shown in figure 7.

Testing the pick-up.

1. Set the zero sequence pick-up value to 0.1 times InGRN by placing a 0.1 in setting 4-1. Set the time delay to 50 ms (setting 4-2).

2. Disable the rest of the units so they do not interfere with the test, by zeroing the settings 1-2, 2-1, 3-2 and 3-5, following the procedure explained in the MGC OPERATION section.

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

Testing the operating time:

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

9. MGC OPERATION

The MGC 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 top 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 top, with **“READY”, “PICK-UP”** and **“TRIP”.** With the cover installed only the push-button **ENTER** can be accessed from outside.

The MGC can be in one of two states:

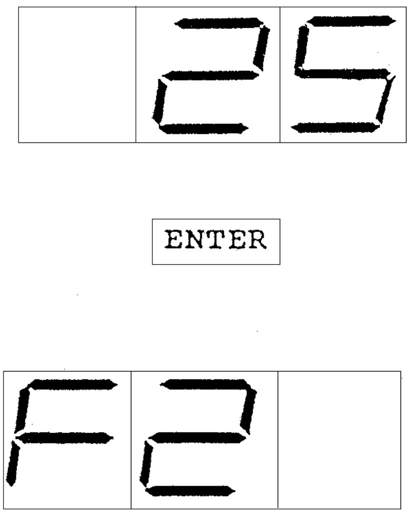
Readings sequence: it provides data on the relay status, symmetrical component values, last trip recording, etc. For its operation only the push-button **ENTER** is required.

Settings sequence: it enables the user to check and change the MGC’s operational settings, as well as to disable the units that may be disabled by the user. It requires all three push-buttons.

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

9.1. Readings Sequence

This is the MGC fundamental sequence and the MGC 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.

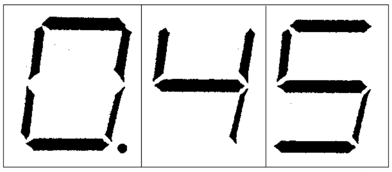


In normal operation, the MGC generally displays the value of one of these functions, which is selected in accordance with the active units. Generally, this reading will be the thermal image expressed as a percentage of the tripping limit; if, for example, we assume that the thermal image unit value is 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 generator 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 generator 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.

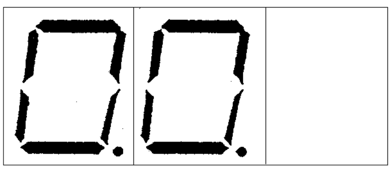
The MGC readings are:

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 MGC 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 MGC status codes are as follows:

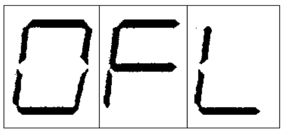
00: Everything O.K.
01: Settings failure. The stored settings are not operating properly.
02: Operation error. The measurement is not correct.
08: General failure.
80: ROM failure. The program memory has failed.
81: EEPROM write failure

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 MGC 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.

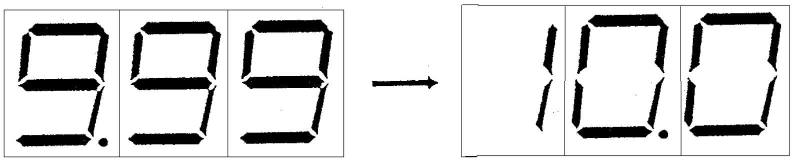


When current stops flowing across the line, the value will have to decrease again to 999 before the OFL message disappears.

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 546%. 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 generator at every moment expressed 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. 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 generator 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 generator 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 on the left, the U (unit) character is shown, the center 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 generator 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 generator 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 generator 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 MGC 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 MGC 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 (Homopolar)	F4 (Homopolar Component)

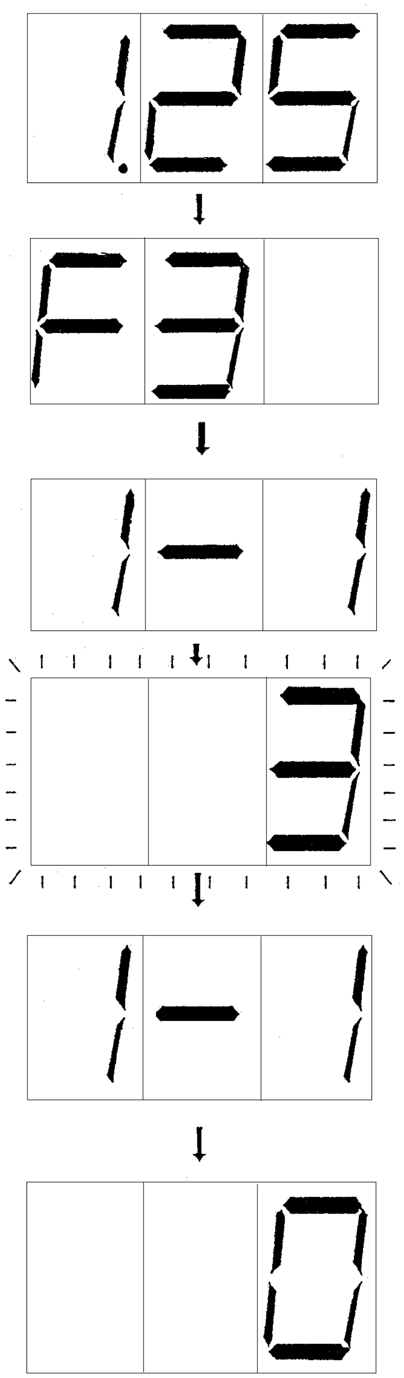
For example, if unit 1 is active, the default reading will be F1, no matter what the status of the rest of the units may be. If we disable this unit (by setting a 0 value in setting 1-2) and unit 2 is active, the default reading will be F2. If units 1, 2 and 3 are not active and unit 4 is active, the default reading will be F4, etc. When all units are not active, the default reading will be F0, Relay Status.

SETTINGS SEQUENCE

The Settings Sequence is the relay state in which the settings of the different MGC 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 MGC 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 MGC 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 MGC 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 MGC 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

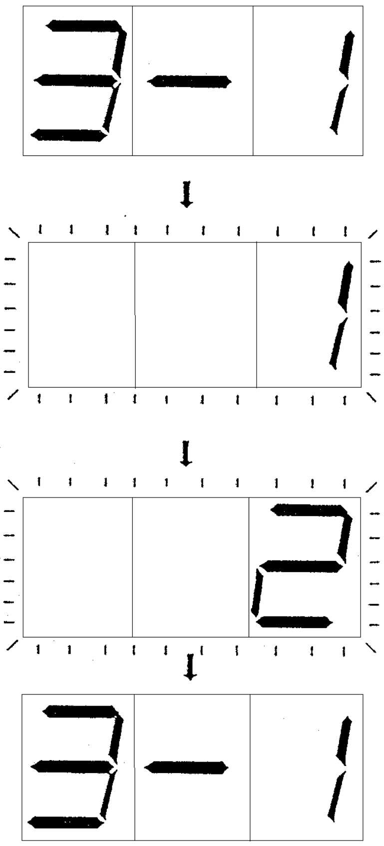
For a detailed description of the units' ranges and operation please see the OPERATING PRINCIPLES Section.

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.

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.

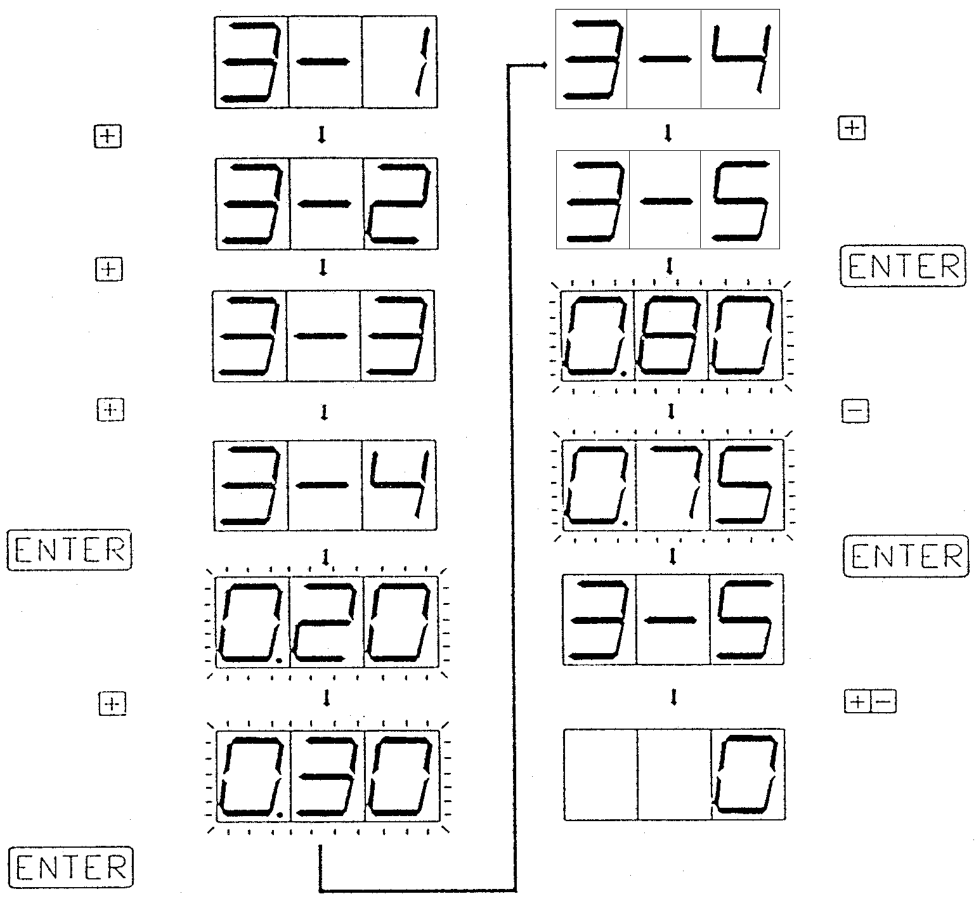
On the following page the change of the two other settings is shown in a summarized way, taking into account that the keys to be pressed would be the ones already mentioned.

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 generator 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.



9.3. Zeroing the Thermal Image Unit

The MGC 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 MGC goes back to the basic status, showing the default reading value on the display.

9.4. Resetting the MGC

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 MGC is operating normally or is in an error state.

MGC in normal operation:

The MGC 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.

MGC in error situation:

When the MGC 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 - Settings failure

When starting the program, the MGC 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 MGC 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 MGC and switching it on again. If this does not fix the error, the whole relay unit must be repaired.

08 - General 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 MGC 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:

$$I_1 = I_2 = \frac{2}{3} I$$

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 MGC 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:

$$I_{eq} = \sqrt{(I_1^2 + K_1 I_2^2)} = \frac{2I}{3} = \sqrt{K_1 + 1}$$

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 0.666 times greater than the current required in the acceptance test.

When single-phase tests are performed, it is important to keep in mind that the design of the MGC causes the analog phase input circuits to saturate when the current in any phase reaches a value 12 times the tap. The maximum value at which relay accuracy can be maintained is 11 times the tap. For this, the maximum accurate value of 11 and 12 in single-phase testing is 11 x (2/3) which is equal to 7.33 times the tap. This permits reaching an equivalent thermal current for the maximum K1 (6) of:

$$I_{eq} = 0.666 * 11 * \sqrt{6+1} = 19.208 \quad \text{times the tap}$$

All tests for greater values must be performed with a three phase system.

APPENDIX 2

SYMMETRICAL COMPONENTS

Introduction

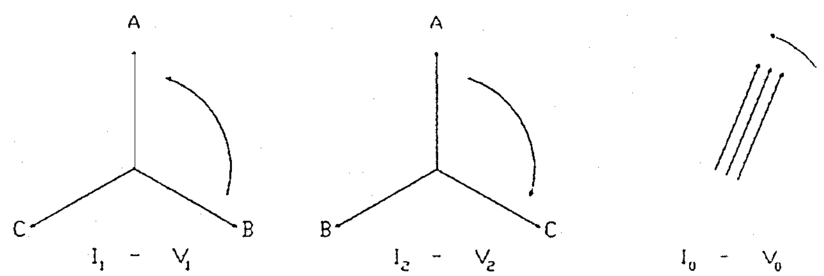
We can break down any three-phase phasor system into a set of three balanced phasor systems, two of them of three-phase type, but with opposite rotation directions to one another, and another one which consists of three balanced and parallel phasors, which rotate in the same direction as one of the previous 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:

$$I_A = I_1 + I_2 + I_0$$
$$I_B = a^2 I_1 + aI_2 + I_0$$
$$I_C = aI_1 + a^2 I_2 + I_0$$
$$I_1 = \frac{1}{3}(I_A + aI_B + a^2 I_C)$$
$$I_2 = \frac{1}{3}(I_A + a^2 I_B + aI_C)$$
$$I_0 = \frac{1}{3}(I_A + I_B + I_C)$$

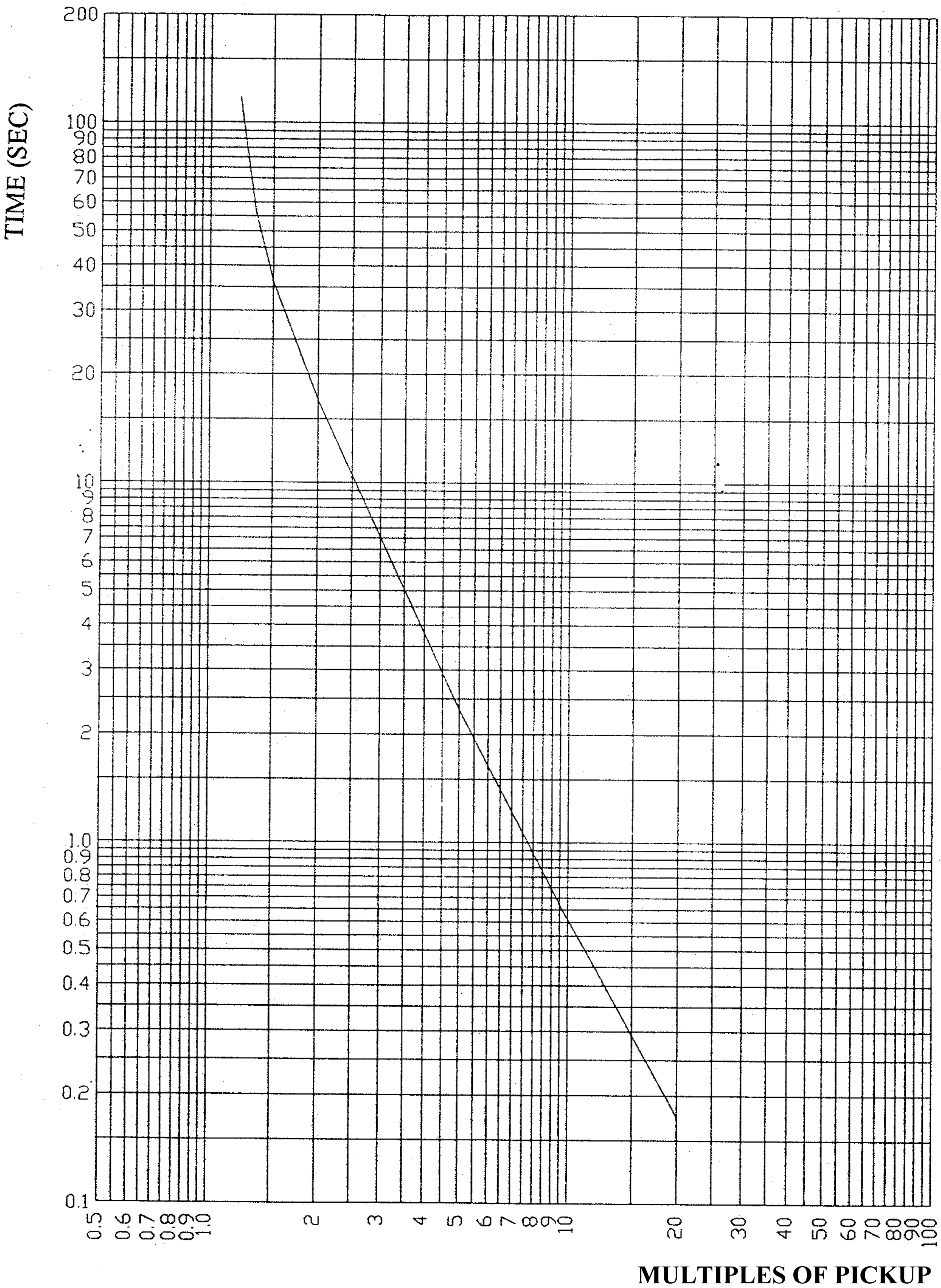


Figure 1. *MGC thermal curve for $\tau 1$ = 60 seconds*

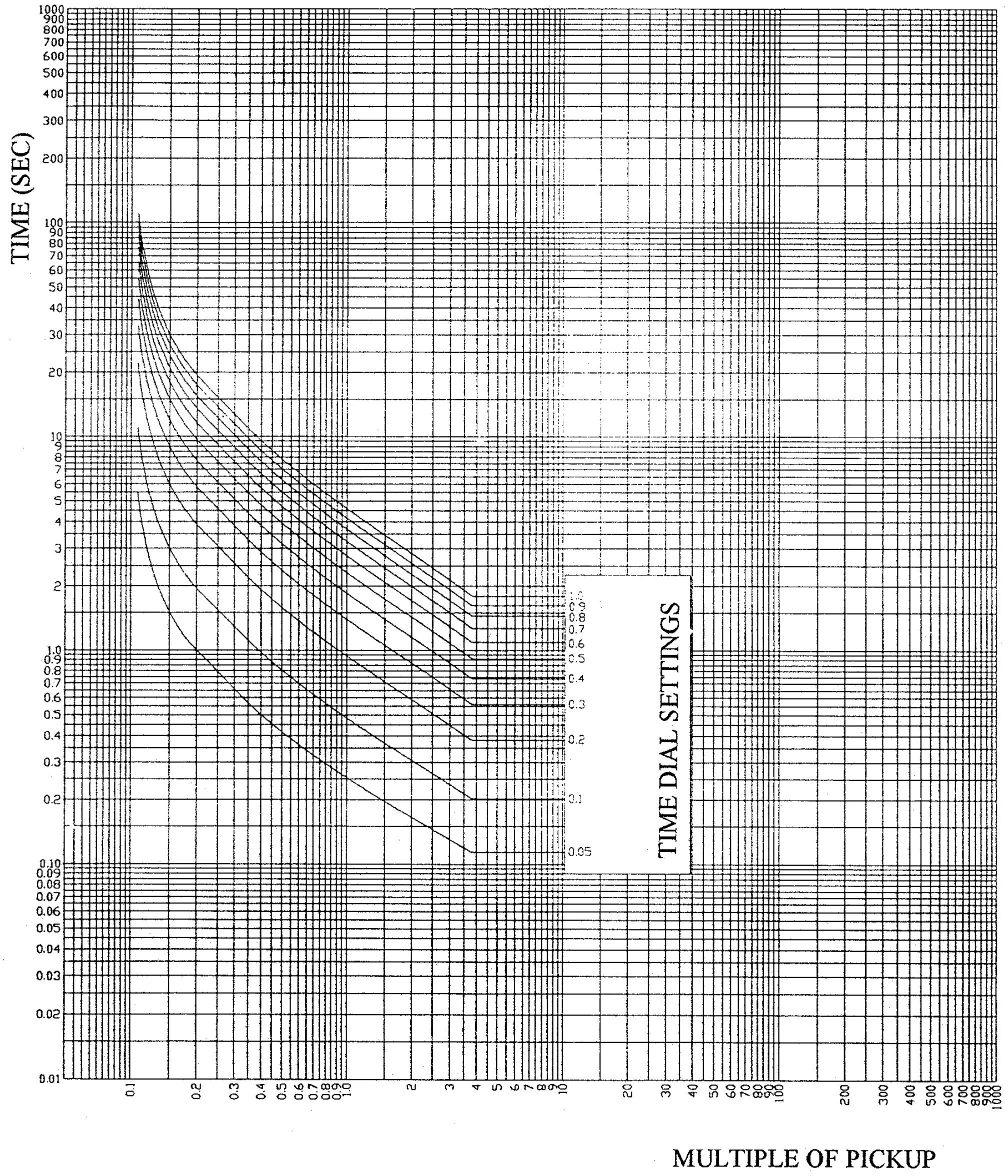


Figure 2. *Inverse time curve family for the negative sequence unit*

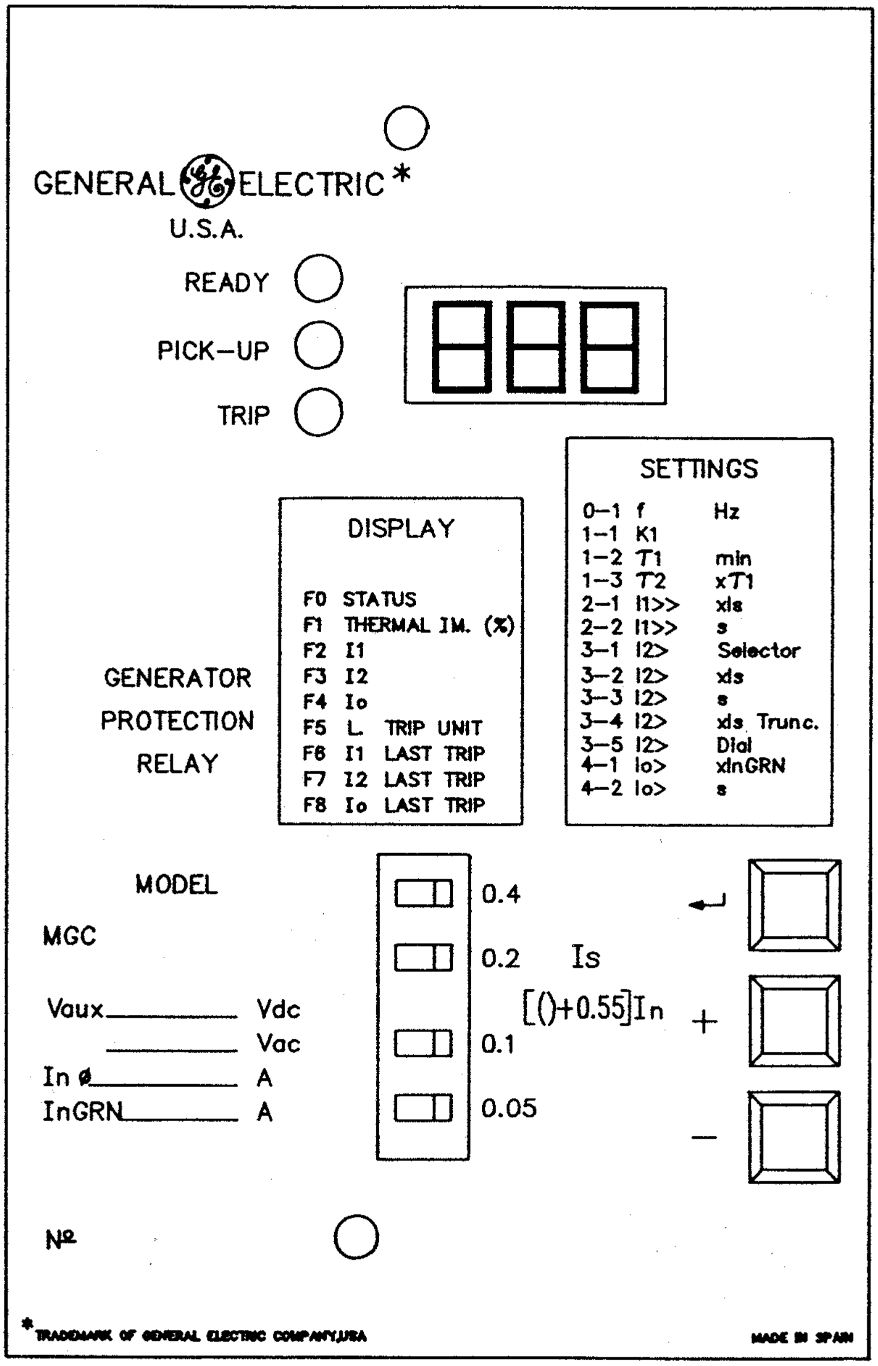


Figure 3. *MGC front plate*

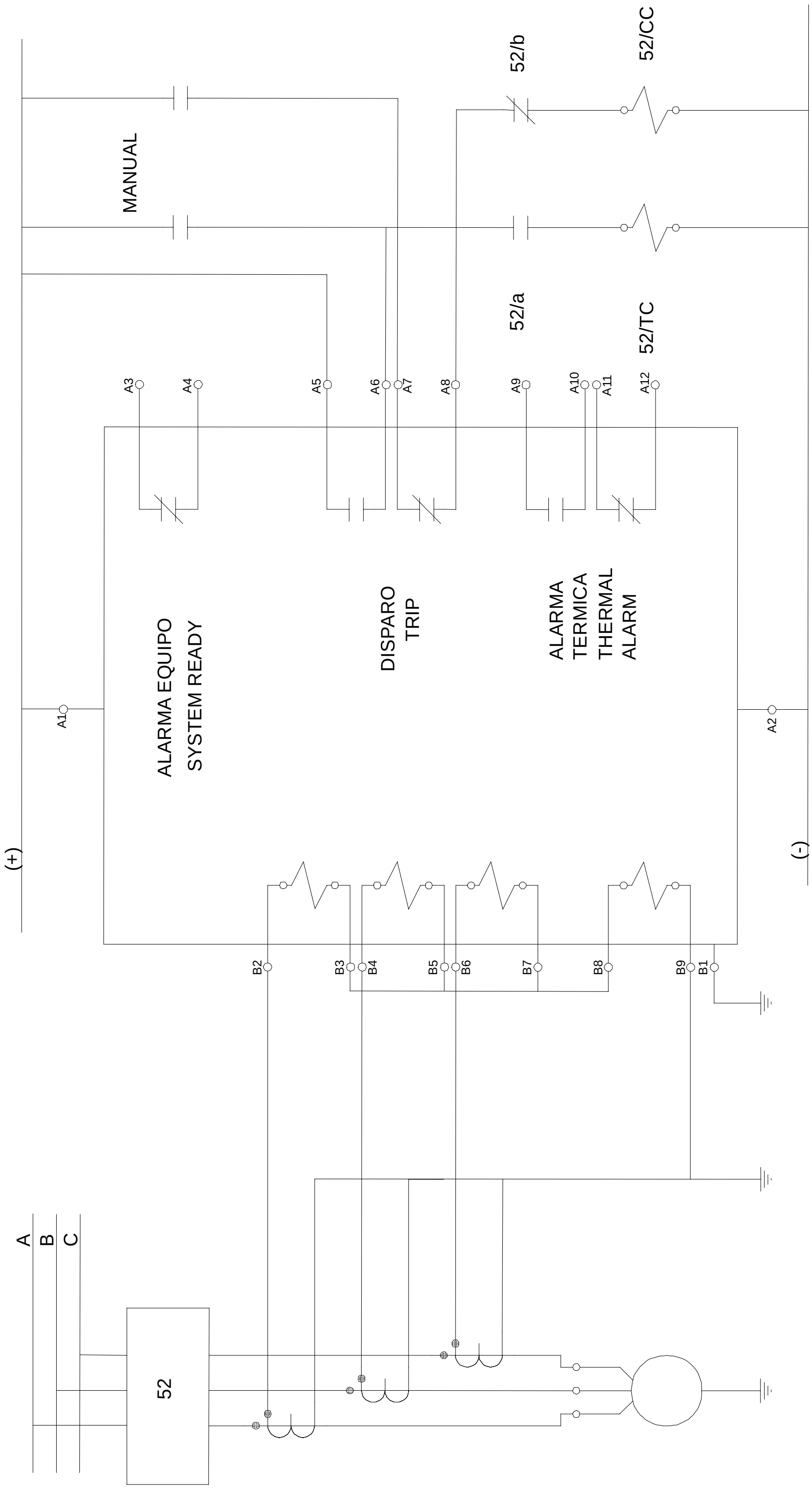


Figure 4a. *MGC connection diagram for non-drawout model*

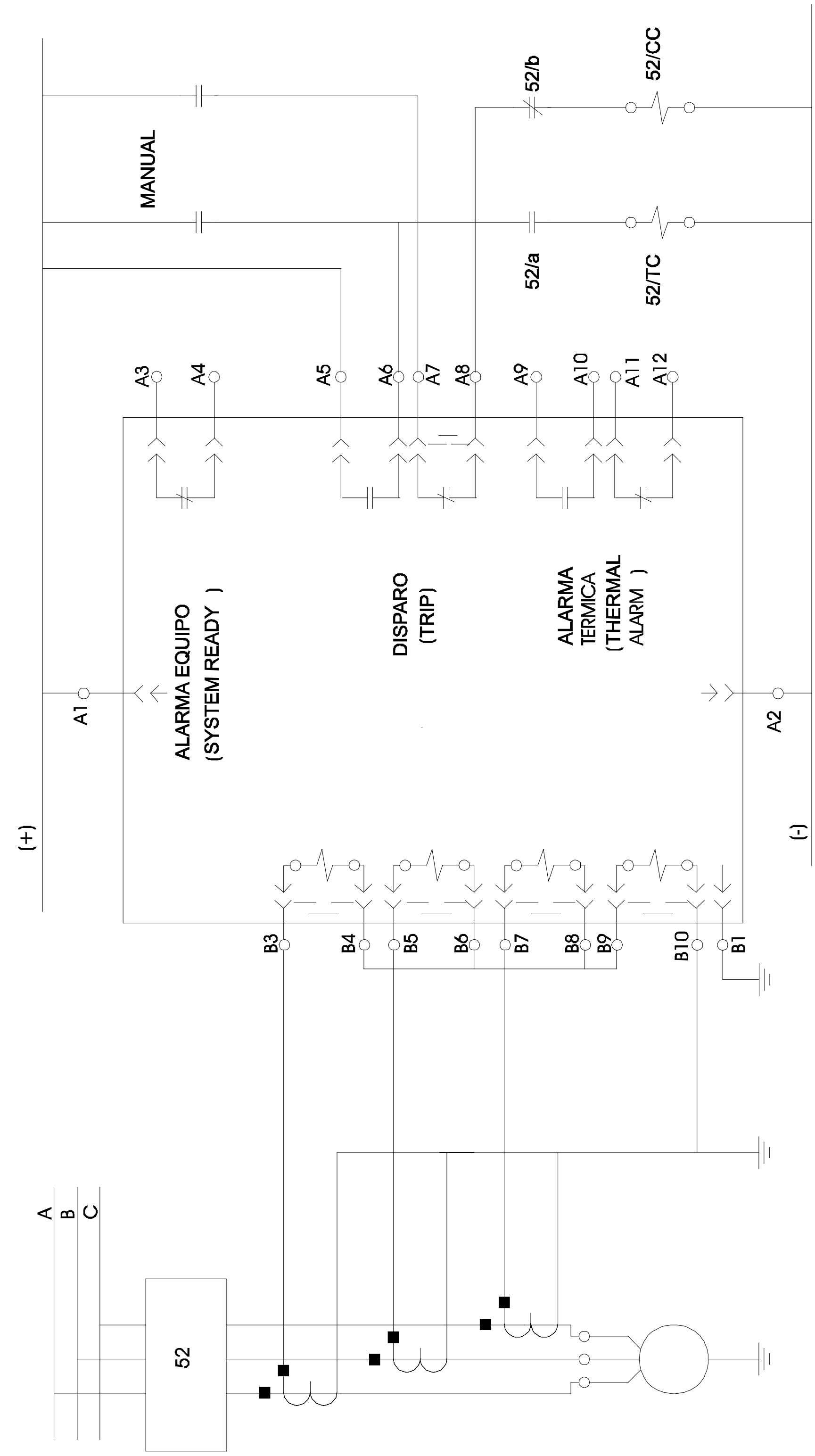
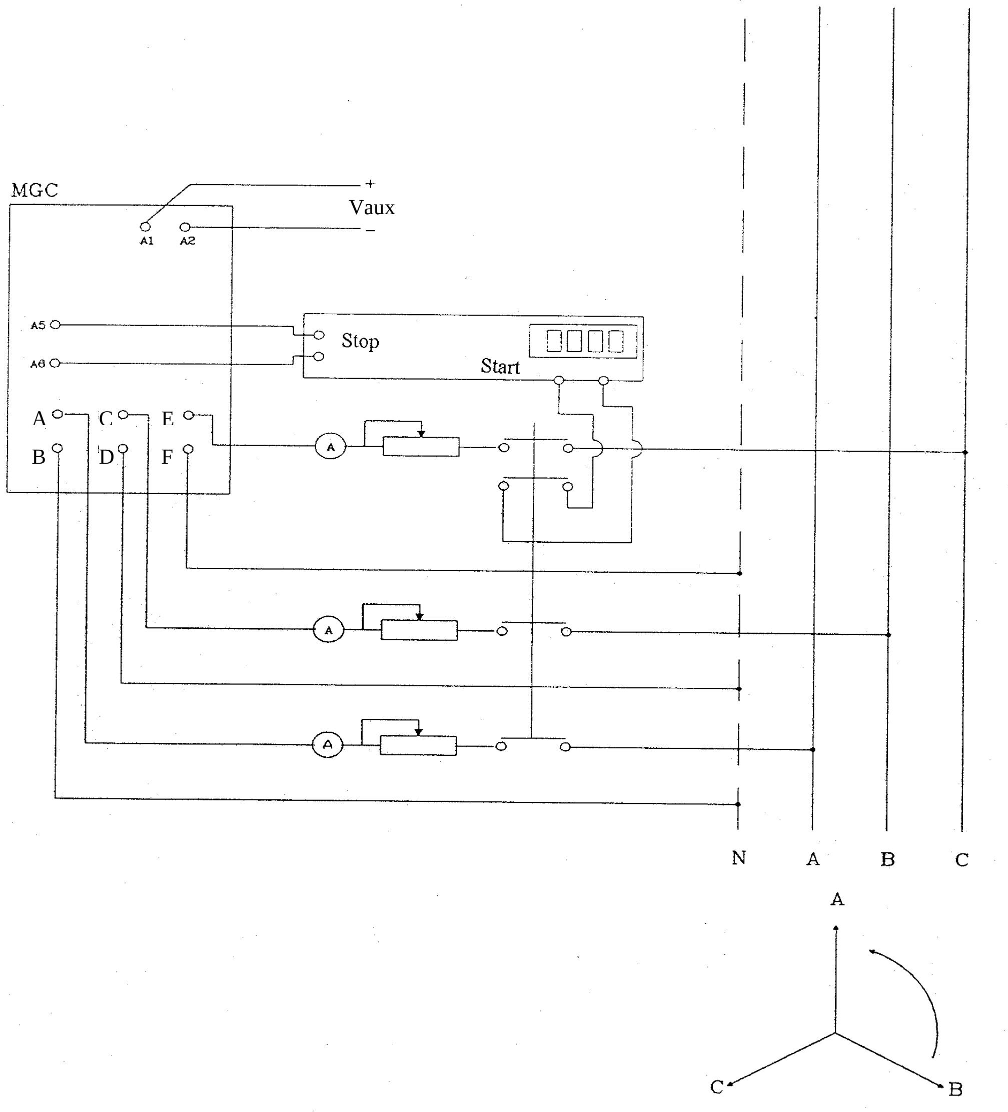
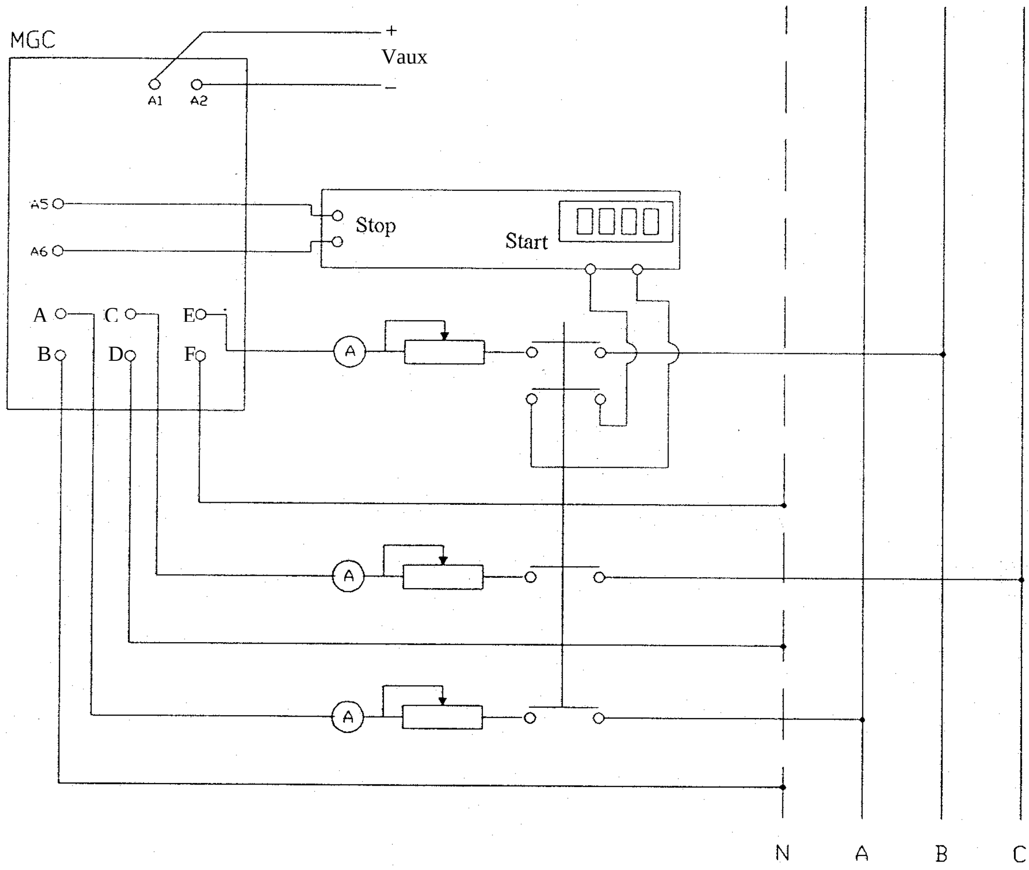


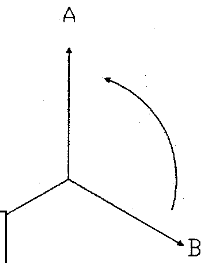
Figure 4b. *MGC connection diagram for drawout models*



	A	B	C	D	E	F
Drawout	B3	B4	B5	B6	B7	B8
Non-drawout	B2	B3	B4	B5	B6	B7

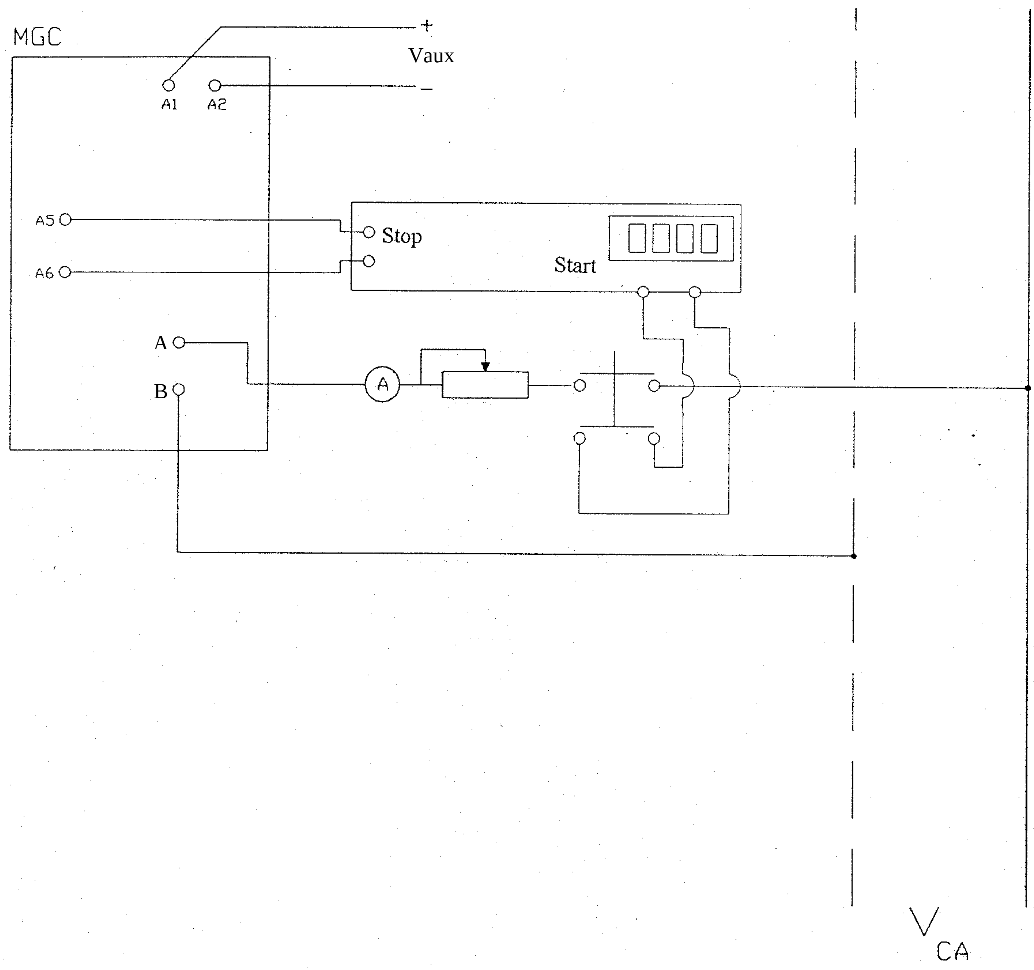
Figure 5. *Connections for testing the thermal image and positive sequence units.*





	A	B	C	D	E	F
Drawout	B3	B4	B5	B6	B7	B8
Non-drawout	B2	B3	B4	B5	B6	B7

Figure 6. *Connection for testing the negative sequence unit.*



	A	B
Drawout	B9	B10
Non-drawout	B8	B9

Figure 7. *Connections for testing the zero sequence unit.*

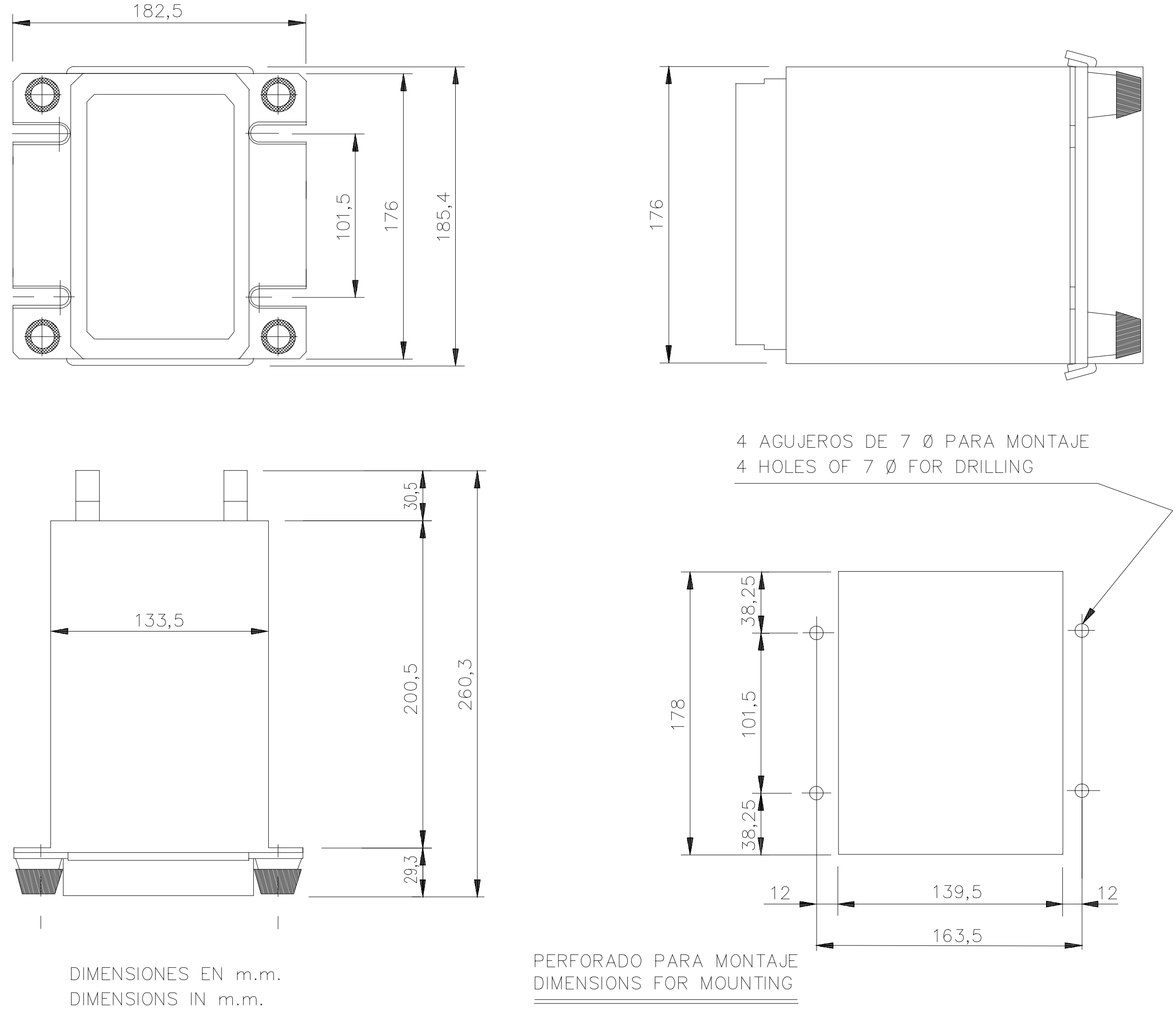


Figure 8a. *Dimensions and mounting of the MGC (non-drawout type) 226B6086F4*

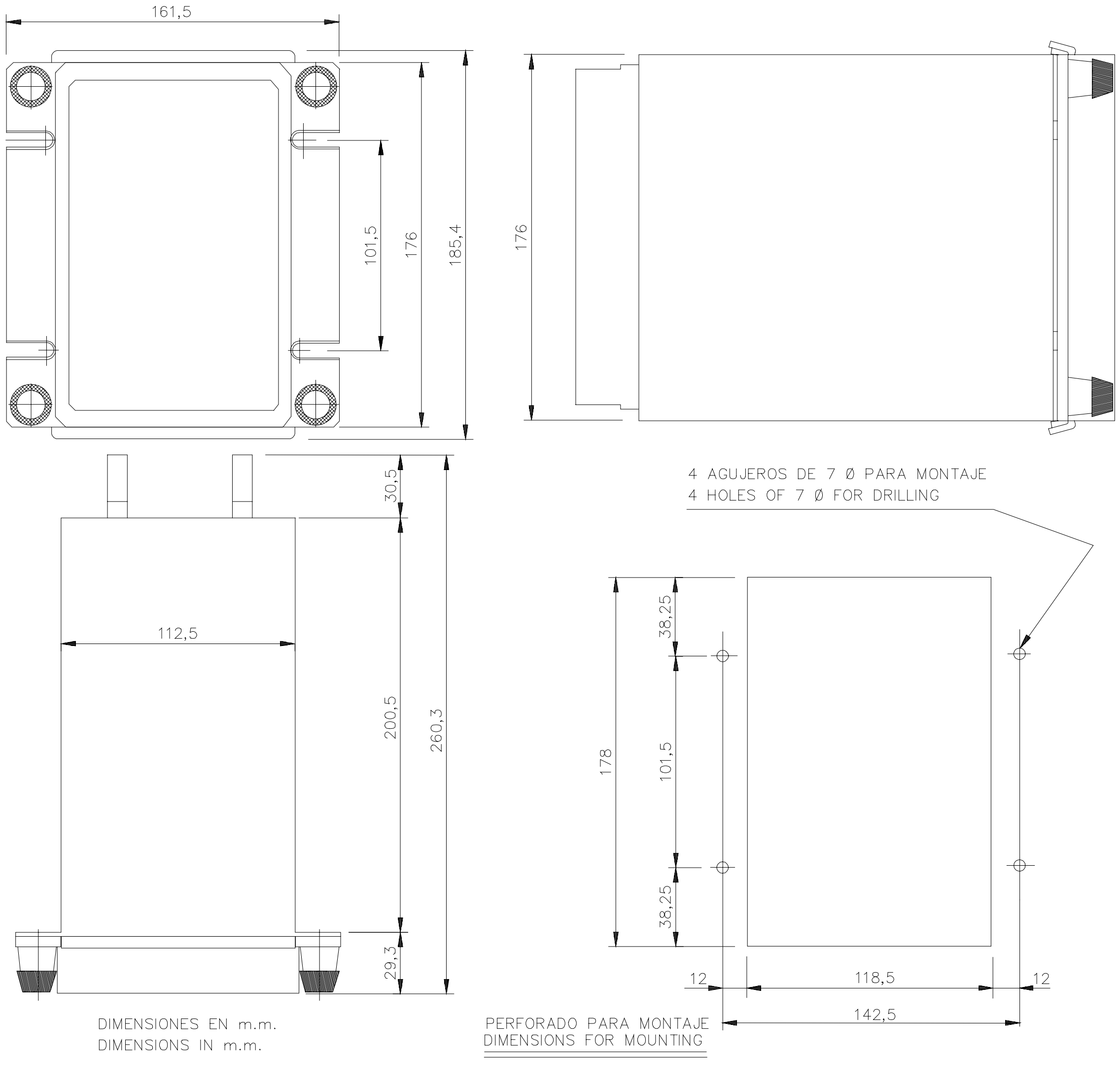
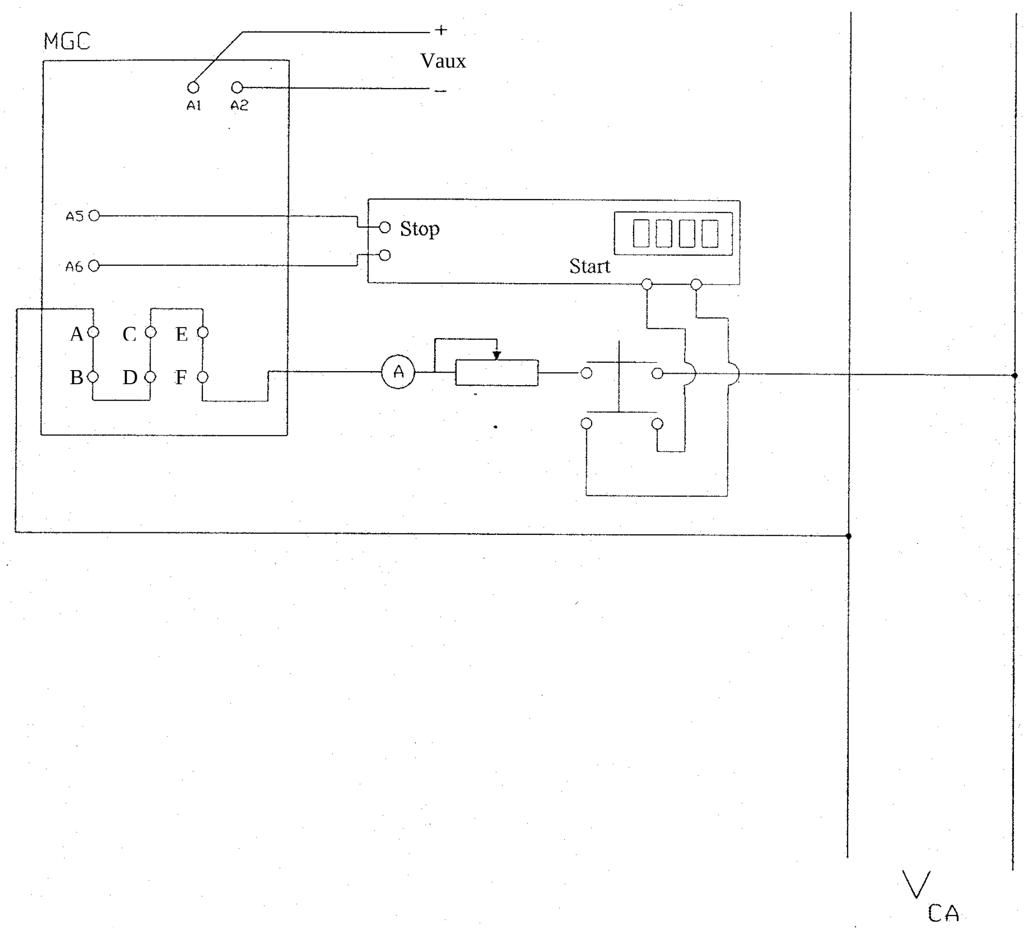


Figure 8b. *Dimensions and mounting of the MGC (drawout type) 226B6086F2*



	A	B	C	D	E	F
Drawout	B3	B4	B5	B6	B7	B8
Non-drawout	B2	B3	B4	B5	B6	B7

Figure 9. *Connections for testing the MGC with a single-phase power supply*