ELECTRICAL MAINTENANCE

DRAWINGS AND DIAGRAMS

TRAINING MANUAL
Course EXP-MN-SE040
Revision 0

ELECTRICAL MAINTENANCE

DRAWINGS AND DIAGRAMS

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1. OBJECTIVES

By the end of this presentation, electricians (or future electricians) will be able to interpret the various representation methods of electrical diagrams, and more specifically they will be able to:

- Use the various types of plans and electrical diagrams correctly
- Associate a set of plans / diagrams to study / troubleshoot an installation
- Identify the elements and components in a diagram
- Distinguish diagrams, selecting the right one to use
- Interpret a logic sequence
- Interpret a combinatory sequence
- Define the symbols to be used according to the type of electrical diagram
- Clarify the choice of a symbol on a plan
- Specify why representation standards are used
- Associate a type of standard with a type of symbol
- Observe the symbol system when drawing up electrical plans and diagrams
- Be familiar not only with the "pure" field of electricity, but also associated, related families such as instrumentation, pneumatics, hydraulics, electronics, systems, etc.
- Be prepared to train non-electricians in electrical diagram representation

2. INTRODUCTION

There are a number of different options for showing how circuits, networks or electrical distribution work. In all cases, this will involve an electrical diagram (or plan) using (standardised!) symbols to represent all or part of the electric installation in question.

This electric installation already exists, or is to be created, so what must it have? **A diagram is needed** in order to build, understand, modify and troubleshoot this same installation. But what type of diagram is required? We will look at the main types used below

DIFFERENT TYPES OF ELECTRIC DIAGRAMS:

- ***Wiring and connection diagram***

  This shows all the connections existing between the various elements in an electric installation.

- ***Schematic diagram***

  To enable the reader to separate and keep track of each step, each level of successive (sequential) operations from the first action (initiation) to the "final act".

- ***One-line diagram***

  Simplification of low and/or high voltage distribution, to provide an "overview" of the installation.

- ***Block diagram***

  This is a "simplified" diagram showing the steps or description of an operation if there is no need to go into detail

- ***Logic diagram:***

  This is a bit like a block diagram. Often used as a troubleshooting tool showing the various possible dysfunctions and the "initiatives" to take and the "directives" to follow according to the different possibilities, occurrences and events in the course of a sequence.

- ***Earthing diagram***

This is a diagram which is very often forgotten after site construction; it shows all the earth/ground distribution systems with the cabling (buried or not), earthing pits, earthing connection points on equipment (by number and connection method). On site it will have an accompanying connection details book.

- ***Other plans/diagrams:***

Electricians use industrial programmable logic controllers (PLC). In the "Automatic controllers" course, we will look at the diagrams for automatic controllers themselves (ladder diagrams), but before drawing up this (final) diagram, here we will look at the systems/methods laying the groundwork for making this automatic controller diagram, i.e.:

Logic diagram: with binary logic, Boolean algebra, Boolean diagrams, Karnaugh maps, …

GRAFCET (Sequential function chart): with the GRAFCET representation standards to enable you to follow and interpret a "*GRAFCET"* diagram. Drawing up a GRAFCET (in its own right) will be covered in the ‘Automatic controllers’ course in preparation for drawing up a ‘ladder’ diagram’.

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3. WIRING AND CONNECTION DIAGRAM

3.1. ANECDOTE

My first electrical diagrams course (back in technical college) was with a wiring and connection diagram (perhaps that's why we're starting with this diagram…).

The teacher sketched electric devices on the board (with approximate symbols), and started plotting "strings" between all these elements. I didn't understand a thing! I wondered what I was doing there; electricity couldn't be for me, especially as immediately afterwards we had to do an exercise for which (obviously) I didn't have a clue about….

Nonetheless I stayed in the "electrical engineering" section and it was just a few months later (yes, only) with another teacher, a replacement, who started talking about symbols, connection terminals, ***schematic diagrams***, all with a sense of "logic", that everything became clear …

Since then, for me, the wiring and connection diagram has remained something of a "muddle", something impossible to read… Of course, I can now decipher a wiring and connection diagram, but it's not a user-friendly form of diagram, it requires attention to follow it, and you can very easily make a mistake when following the wires between the connections

As to the teaching method for the schematic diagram…, when I returned to the same college a few years later, I saw my ex-teachers again, but since I was an electrical engineering teacher myself (I didn't remain as a teacher for long, I went over to industry the following year), I came across a particularly high number of pupils aiming for a vocational qualification in electrical engineering.

My main class (as the primary teacher) was a penultimate-year technical class, and I can assure you that all, without exception, were very quickly able to draw quality electric diagrams. Furthermore in the course of the academic year, one Saturday morning (we did 40 hours a week in technical classes), I was "ordered" by my pupils not to go at midday, but to put myself at their disposal!!?

The whole class (including boarders who were supposed to go home for the week-end), as well as me, went to the local café for a drink/lunch, organised by these same pupils. A nice surprise indeed, and as far as I know, no other teacher was ever treated to that favour: and in addition, all those whom I've met since then have all made a career in the field of electricity.

So much for the "anecdote" part…

3.2. PRINCIPLE OF THE WIRING AND CONNECTION DIAGRAM

This is the first "wiring" method used.

We represent devices and apparatus on a plan, and plot the ‘wires’ between the elements represented directly to the device or to terminals (terminal block) belonging to this device.

We can indicate the type of wire used (cross-section, length, type of cable, etc.), its colour (of insulant), with the thickness of the line relating to the current intensity: a thick line for a power circuit, and a thin line for a control circuit.

It is clear that for a ‘small’ installation, a wiring and connection diagram may be "appropriate", but if we go on to something substantial, this same wiring and connection diagram will give us something unreadable.

Example of wiring and connection diagram:

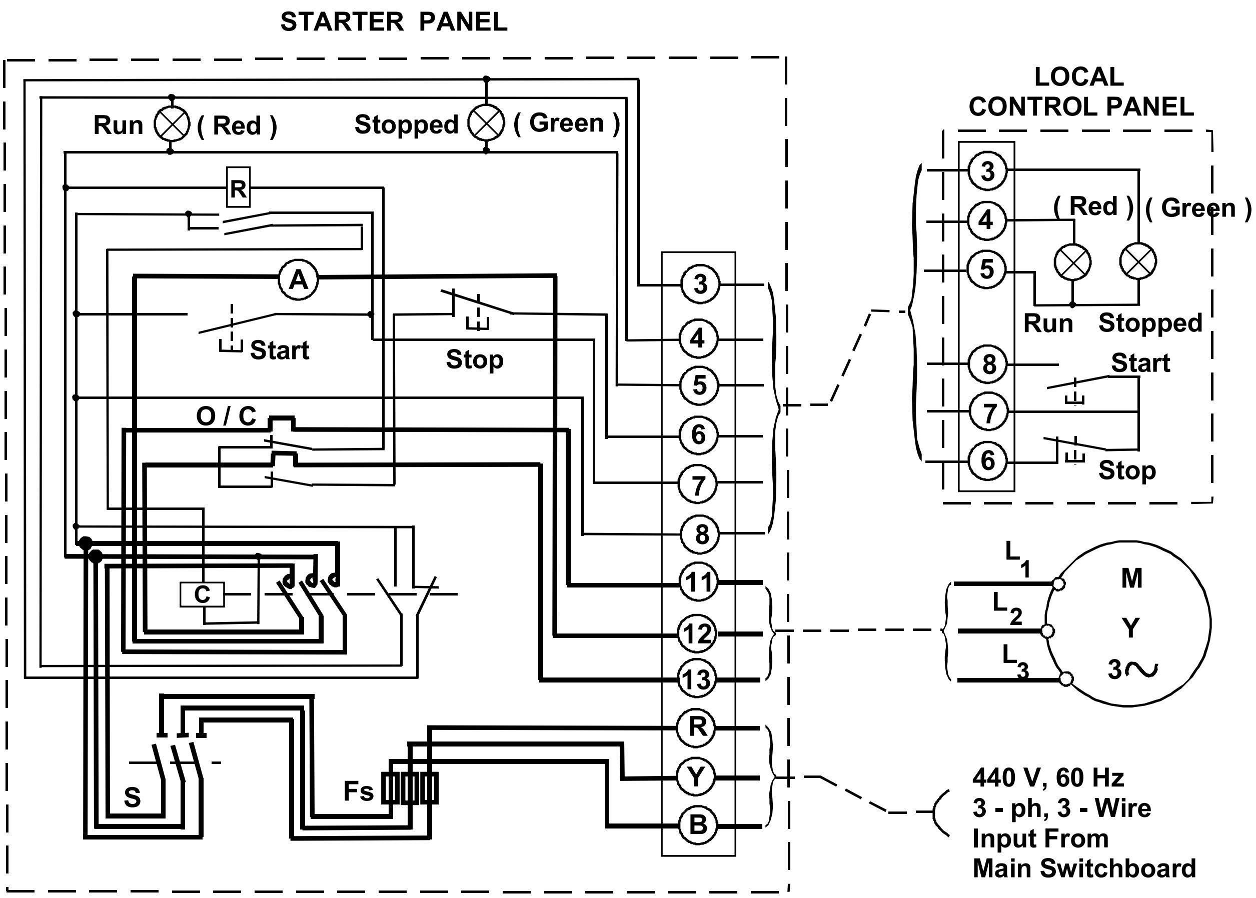


Figure 1: Example of wiring and connection diagram

This diagram is for a motor control, with one direction of operation, a run/stop control on the main control unit, and also with a local control panel. "Run" and "stopped" indication signals at both control points

3.3. COMMENTS ON WIRING AND CONNECTION DIAGRAM

This type of diagram will, however, be very useful for wiring engineers, those who connect up the equipment.

In (electric cabinet) wiring workshops, the wiring engineer is not necessarily an electrician; indeed very often it is someone who doesn't have a great understanding of electricity. They need only know (for example) that a 2.5 mm² wire connects terminal 3 on equipment 'A' to terminal 5 on equipment 'B', and so on.

Furthermore, the engineering and design dept. produces wiring plans for these same wiring workshops.

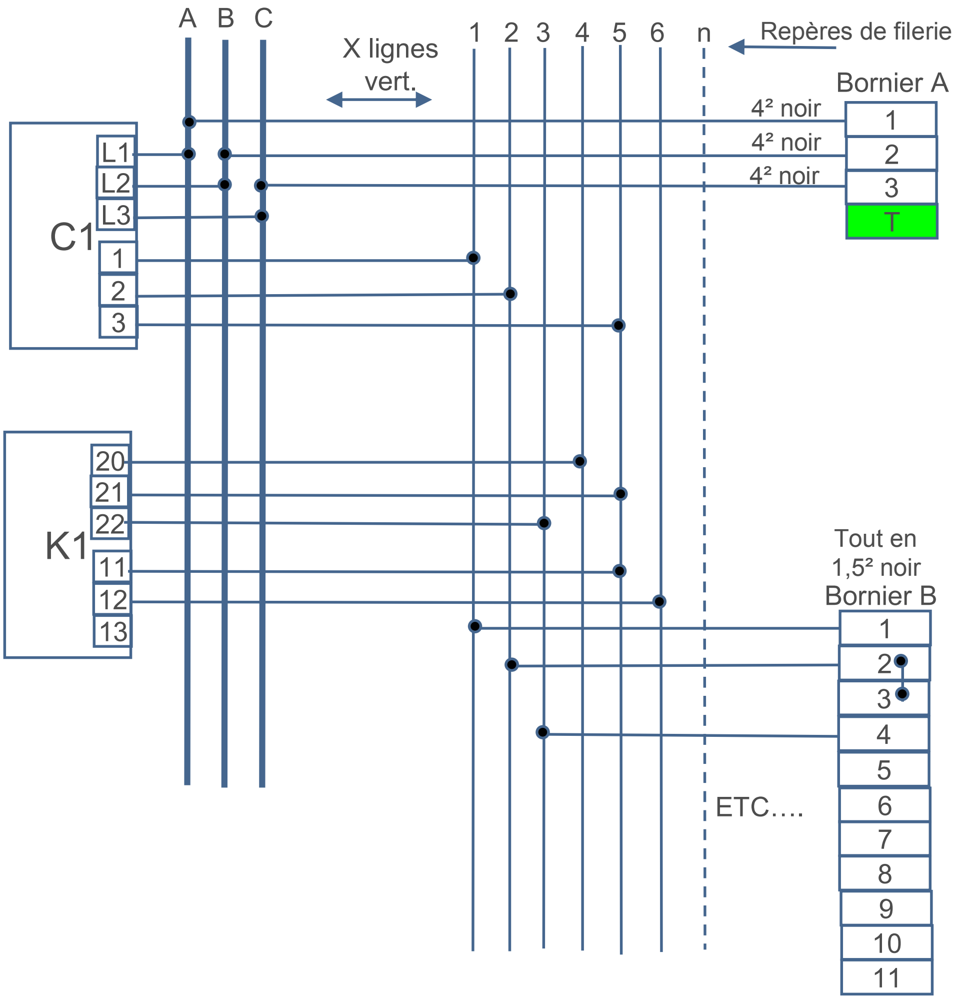


Figure 2: Example of wiring diagram

The type of diagram above is just a rough of "something" resembling a wiring diagram; every manufacturer and workshop (practically) has its own method. This example is to show you that anyone can connect a wire from one point to another, insert a wiring tag (you will no doubt have noticed that wires are tagged…), select the cross-section and the connection wire colour, as long as everything is indicated.

For troubleshooting, maintenance and servicing electricians do not need a wiring diagram, or the wiring and connection diagram, which would hardly be practical. At the most they will need the wiring and connection diagram to find their way around certain connections (that they will have identified in advance).

However, in certain cases, there is nothing else but the wiring and connection diagram! Certain "packages", in particular air conditioning equipment cabinets (‘made in USA’ or using US method) have a wiring and connection diagram stuck on the inside of the door. And even if you look up the service manual, you will only find this same wiring and connection diagram; in this case, there is nothing for it but to "grin and bear it"….

4. SCHEMATIC DIAGRAMS

This is the diagram most commonly used by electricians, for designing diagrams (in functional analysis), investigation, modifications and troubleshooting. Of course we are talking about conventional hardware, with relays, contactors, controls and specific equipment automatic systems.

The software with automatic controllers sometimes uses what is (in my opinion) a certain form of schematic with the "ladder diagram", for control circuits.

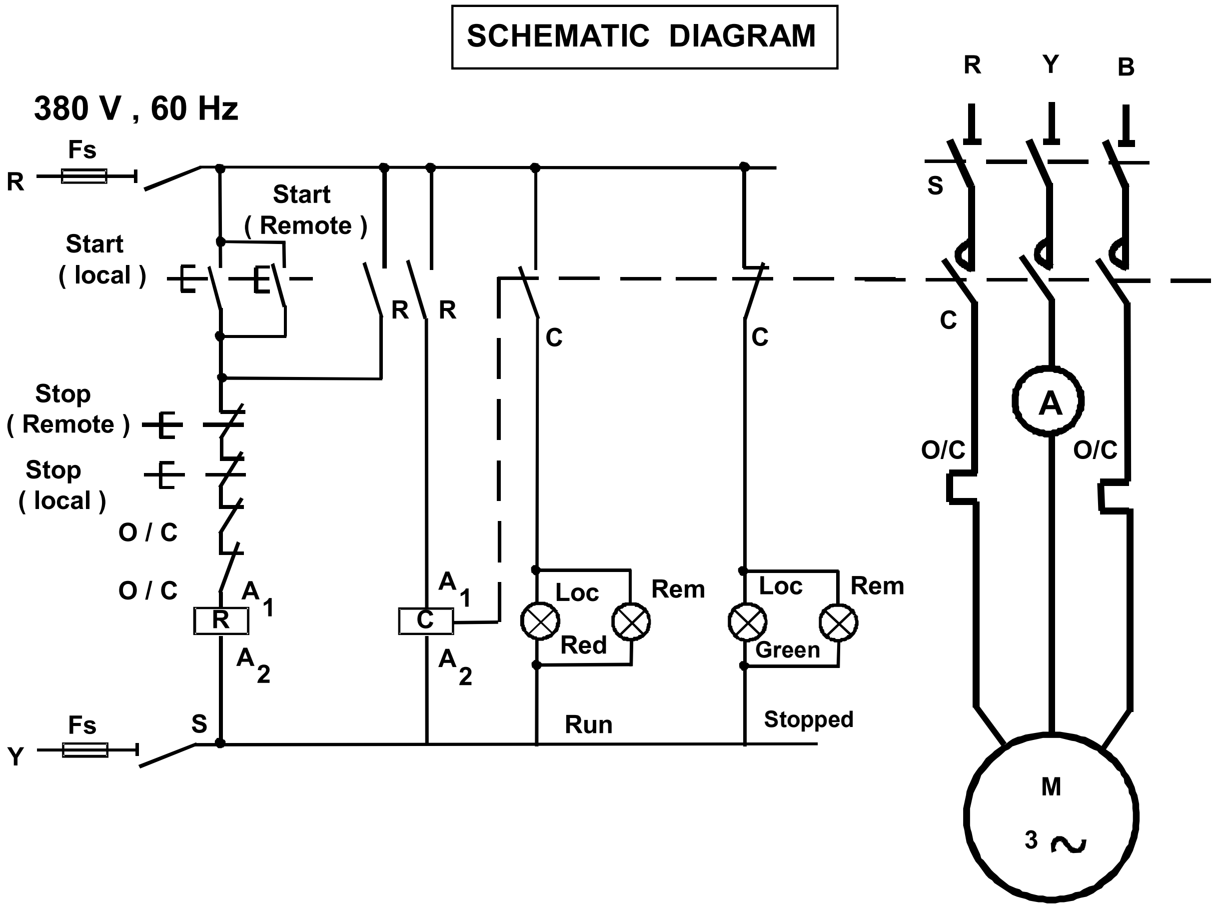


Figure 3: Example of schematic diagram

The schematic diagram above is for exactly the same thing as the wiring and connection diagram in the section above: a motor starter, one direction of operation, 2 Run – Stop control stations and 2 Stopped / Run indication signals.

As for the wiring and connection diagram, the schematic diagram has a ‘power part’ marked by thick lines, and a control part marked by thin lines.

4.1. CONVENTIONS OF PRODUCING A SCHEMATIC DIAGRAM

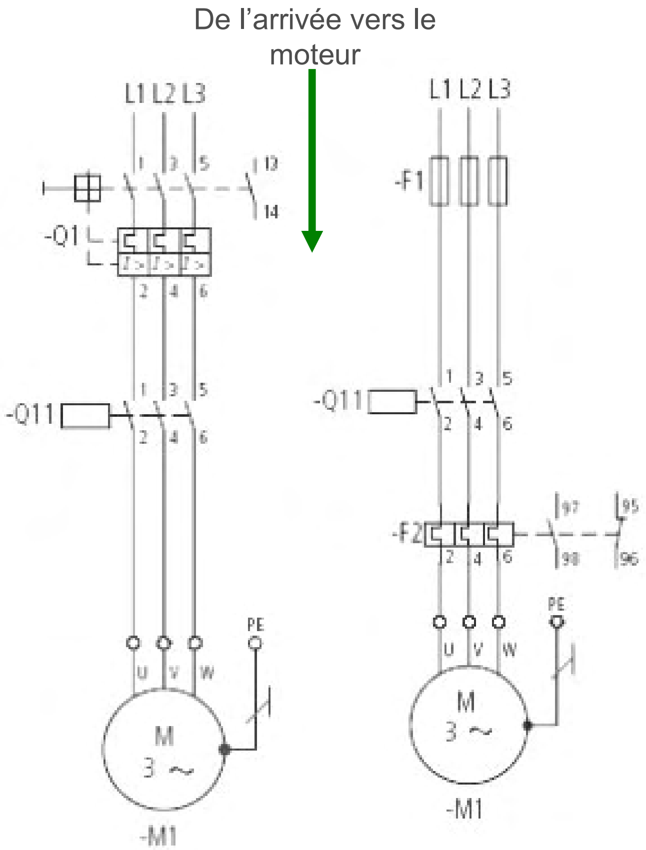
There are certain conventions (practically) common to all countries, and therefore all types of standards. You will need to observe these if you produce a schematic diagram yourself.

4.1.1. Power circuits and control circuits:

- The diagram as a whole encompasses all of a given (force/power) equipment's protection, cut-off and control devices: this may be a motor, an actuator, a heating resistor, a sub – distribution cabinet, etc.
- Another "force" equipment will have its own schematic diagram on a separate sheet
- Wherever possible, power and control are grouped together on the same sheet. Control on the left, power on the right or vice-versa – there are no constraints on this point.
- The common parts, i.e. automated systems, locks, interfaces with other equipment, etc. are covered by a schematic diagram (control part) on separate sheet(s). This may even involve an independent automatic controller diagram.

4.1.2. Power circuits

- All devices (isolator switch, switch, breaker, etc.) are physically within the same envelope: the same cabinet or even panel or same box, etc.
- All connections are represented, with thick lines,
- Devices are represented in *logical order in the direction of the current*, from ***top to bottom***. From the motor input terminals, via (in order) the isolator / switch, fuses or breakers, contactor (or breaker contactor), relay(s) and terminals. Left to right representation is also possible.
- Auxiliary contacts for power devices are represented (or not) on the same axis as the main poles or beside the device concerned
- Number of poles according to the use required: single (Ph + E), two-phase, three-phase, four-phase (and even six-phase)
- The whole 'line' is at the motor's direct or alternating operating voltage, from a few volts to 11 kV (this is the maximum voltage that I have seen for a motor).



This power diagram relates to a direct starting motor with 2 protection solutions

Breaker protection (Q1), engaged by contactor (Q11)

or

Fuse protection (F1)
Engaged by contactor (Q11)
Triggered by thermal relay (F2) upon fault

Note:

- The auxiliary contacts

- The ***earth connection, which is always represented on the power circuit***

Figure 4: Example of power

4.1.3. Control circuits

- To draw a control circuit, we start with 2 parallel horizontal or vertical lines, with sufficient space between them to fit in the control components. These are the 'distribution bars', with '+' and '-' polarities with DC, and a marking of your choice with AC.

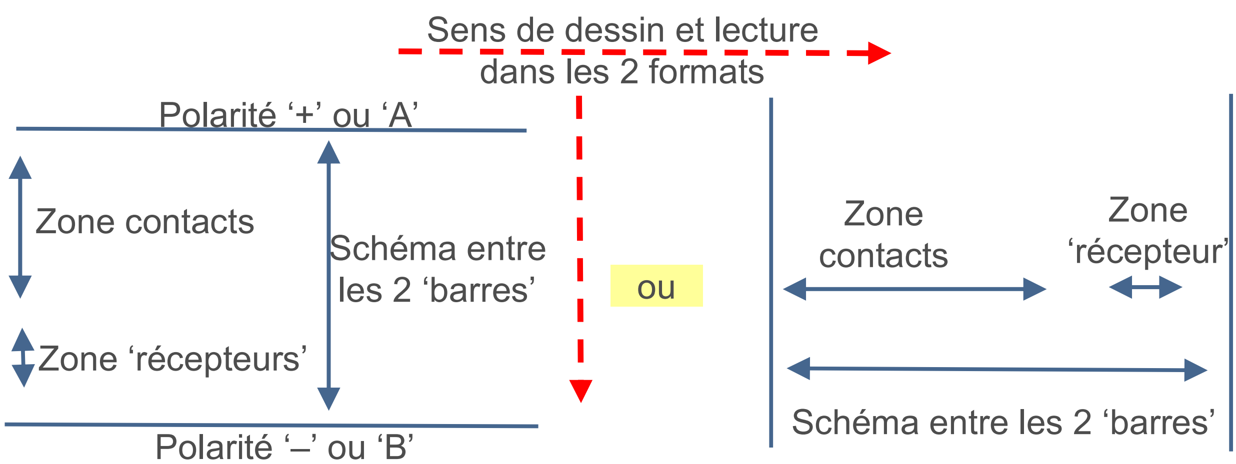


Figure 5: How to draw and read a schematic diagram / control

- Each sequence must be drawn from left to right and top to bottom – and this is always the case, everywhere.

- Each step must strictly follow the order of occurrence when read from left to right (or top to bottom

- When the number of steps, sequences and functions becomes too great to be contained on the same page, you need to continue on other pages, taking care not to dissociate logic sequences. Always group together on the same page a series arrangement of contacts, or an intermediate parallel arrangement.

- Make the necessary links and notes between pages for ease of comprehension

- The upper part of the diagram (with horizontal distribution bars) and the left-hand part (with vertical bars) are reserved for contacts and controls (push-buttons, travel limit switch, relay contact, time-lag, etc.).

- The lower part of the diagram (with horizontal distribution bars) and the right-hand part (with vertical bars) are reserved for receivers (relay coil / contactors, lamps, resistors, etc.)

- All contacts and elements in series must, wherever possible, be drawn on the same line, along with the element they control.

- When the number of contacts in series becomes too high (to enter between the 2 distribution bars), insert logical links ***without crossings***. A control circuit with crossings (except when there really is no other way) is a poor diagram.

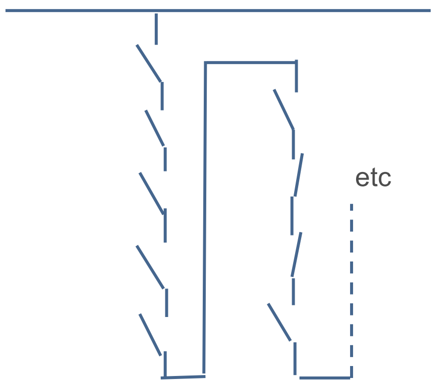


Figure 6: Links in series

- All contacts and elements in parallel must, wherever possible, be drawn on the same line - on the same level - to highlight this parallel arrangement function.

- As all receivers (coils, lamps, etc.) are actually operating elements receiving polarities or voltage, they must be drawn on the same line, for ease of identification.

- Any 'desire' to align a contact with 'its' actuating (relay) coil, for the simple reason that they belong to the same 'box', must be avoided

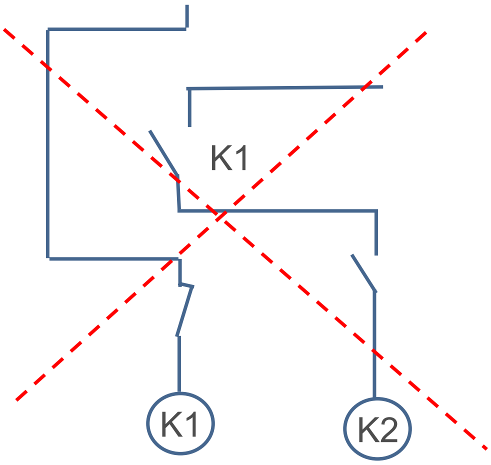


Figure 7: Watch out for alignment of contacts

- All receivers controlled / powered between the same two distribution bars are at the same voltage.

Certain schematic diagrams of control circuits may have more than one distribution 'network'. In this case the voltage is indicated on each page, on each bar: make sure not to mix the voltages.

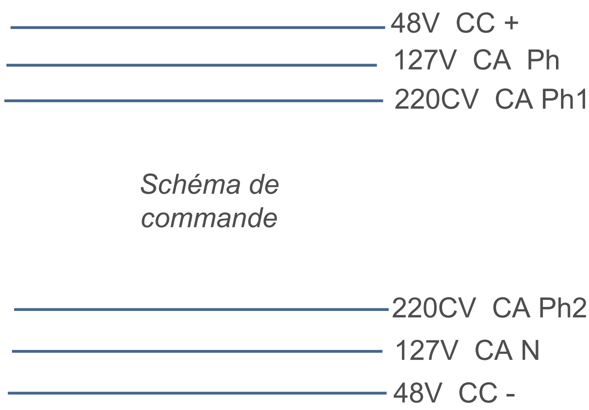


Figure 8: Multi-distribution diagram

In this case (multiple distribution bars), the 'corresponding' bars are on the same level, as indicated in the sketch

- Devices and protectors supplying control circuits (i.e. distribution bars) may require transformers or converters (AC to DC for example); there will also be switches, fuses, breakers, etc. They may be represented equally well in the 'power circuit' or 'control circuit' part. *Obviously, there is no problem if everything is on the same page*

What we have seen above has given us an overview of the "primary" conventions. There are other conventions specific to manufacturers, to the standards of a particular country, or a particular user developing its own rules, but these are "secondary". As long as you observe the ones we have looked at, you will be able to understand and draw a schematic diagram.

And, as a free piece of advice, try to avoid this type of "bridge" opposite on schematic diagrams; on certain diagrams, after a number of copies, reduction etc., it is no longer clear whether it's a connection or a bridge…

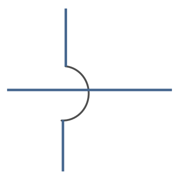
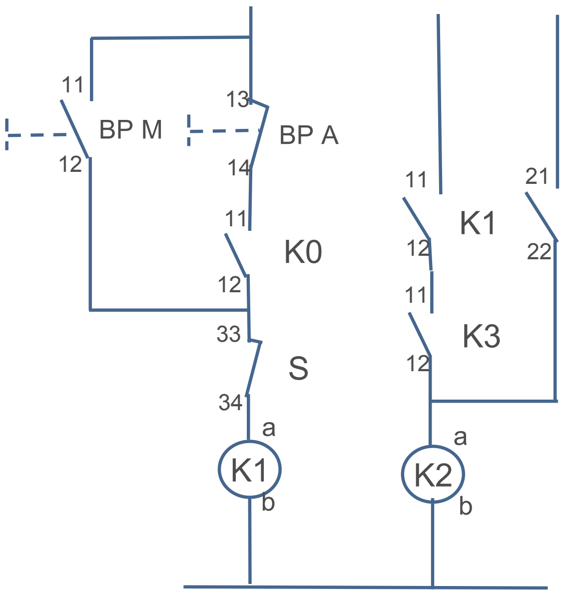


Figure 9: "bridge" to be avoided in diagrams

4.1.4. Identification principles

Unlike the wiring and connection diagram, the basic principle is to be able to have all the parts of an assembly (for example a relay coil and its 'x' NO or NC contacts) spread throughout the diagram(s).



The "assembly" constraint is the association on the same control of 'x' contacts and control functions.

Everything that belongs to the same 'box' (relay coil and its contacts) will have the same identification and tag whatever its location in the diagram. *The only difference, on certain diagrams, is the letter and/or number for the terminals themselves – the device and its components always keep the same basic identification.*

Figure 10: Example of identification and tagging of terminals on control circuit

Electricians use this diagram to make repairs. Following each step of the sequence, they can understand not only how it works, but can also see where it is going wrong.

Let's take another look at the one-way motor

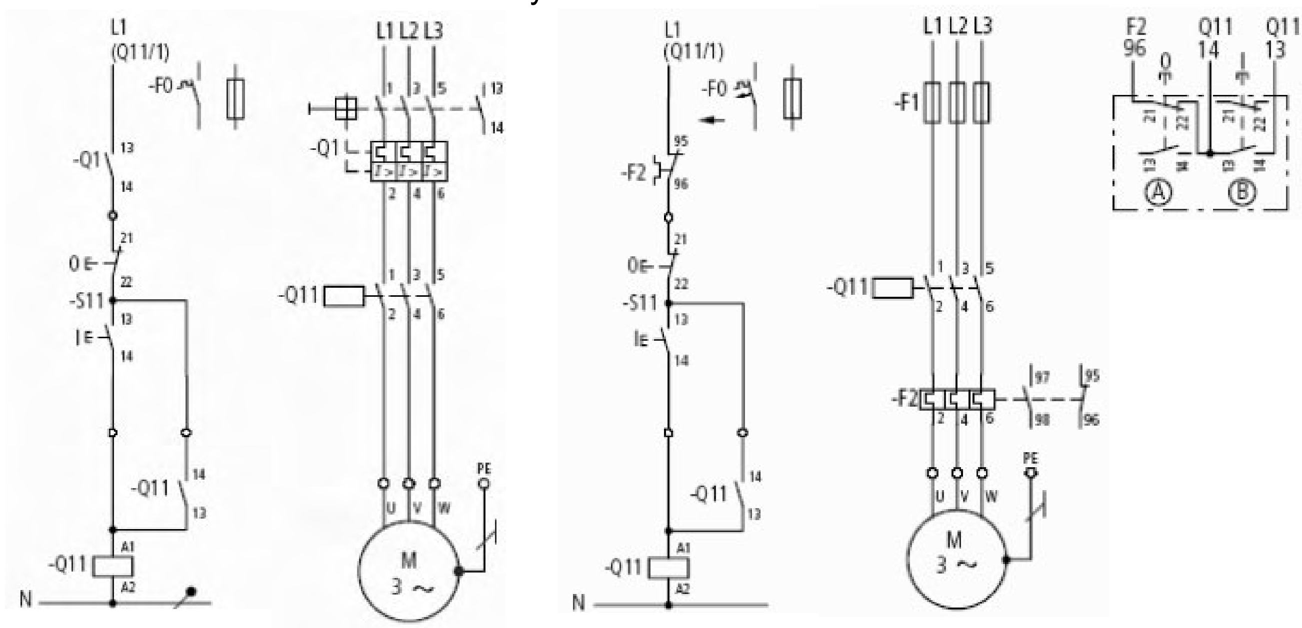


Figure 11: Schematic circuit of one-way motor – a control panel

In the left-hand diagram, we have direct protection on the power circuit by the breaker, which is triggered on the control circuit by the breaker auxiliary contact Q1

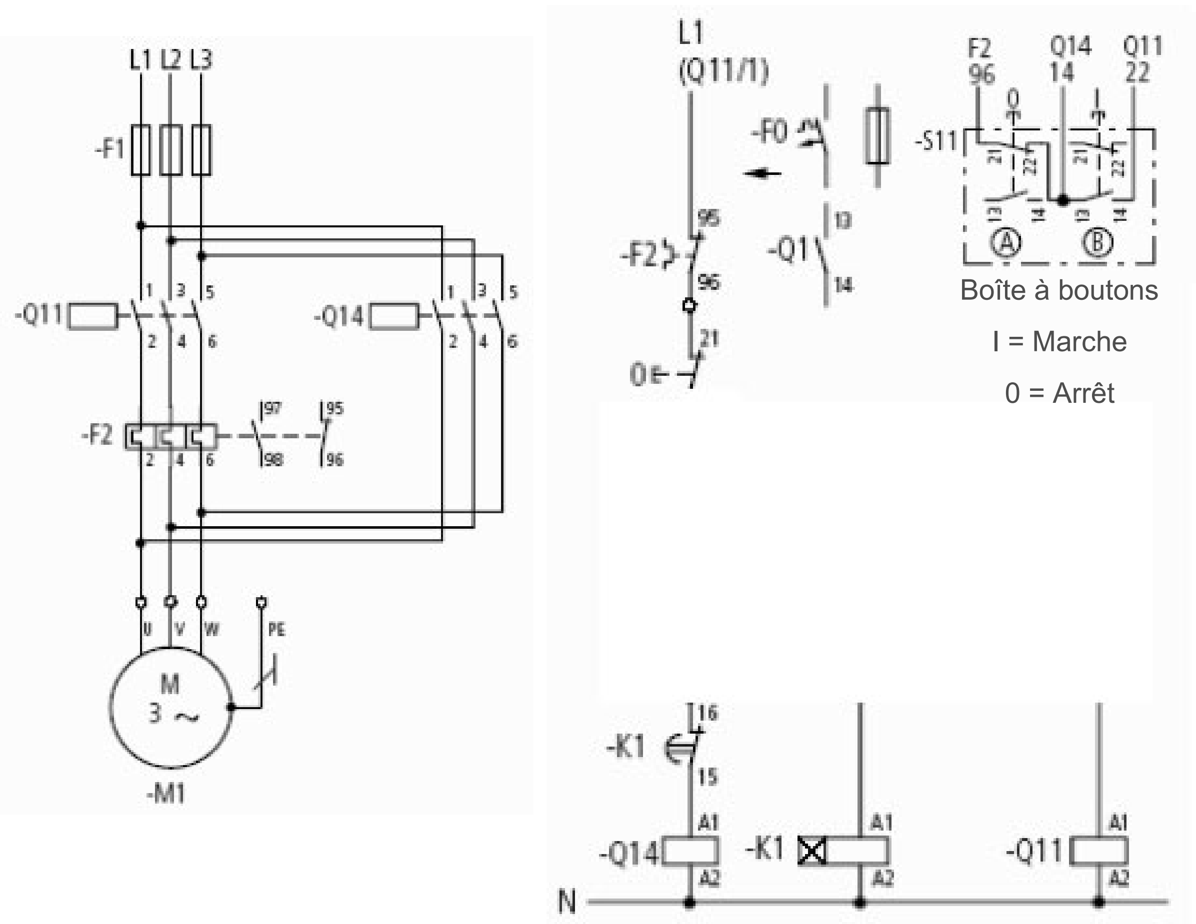
The left-hand diagram is with fuses and thermal relay, with the control panel represented in wire form for this diagram.

Fuse F0 is to be incorporated in the control circuit, if there are no other protectors provided for this purpose.

4.1.5. Exercises –schematic diagrams

Now it's your turn with schematic diagrams

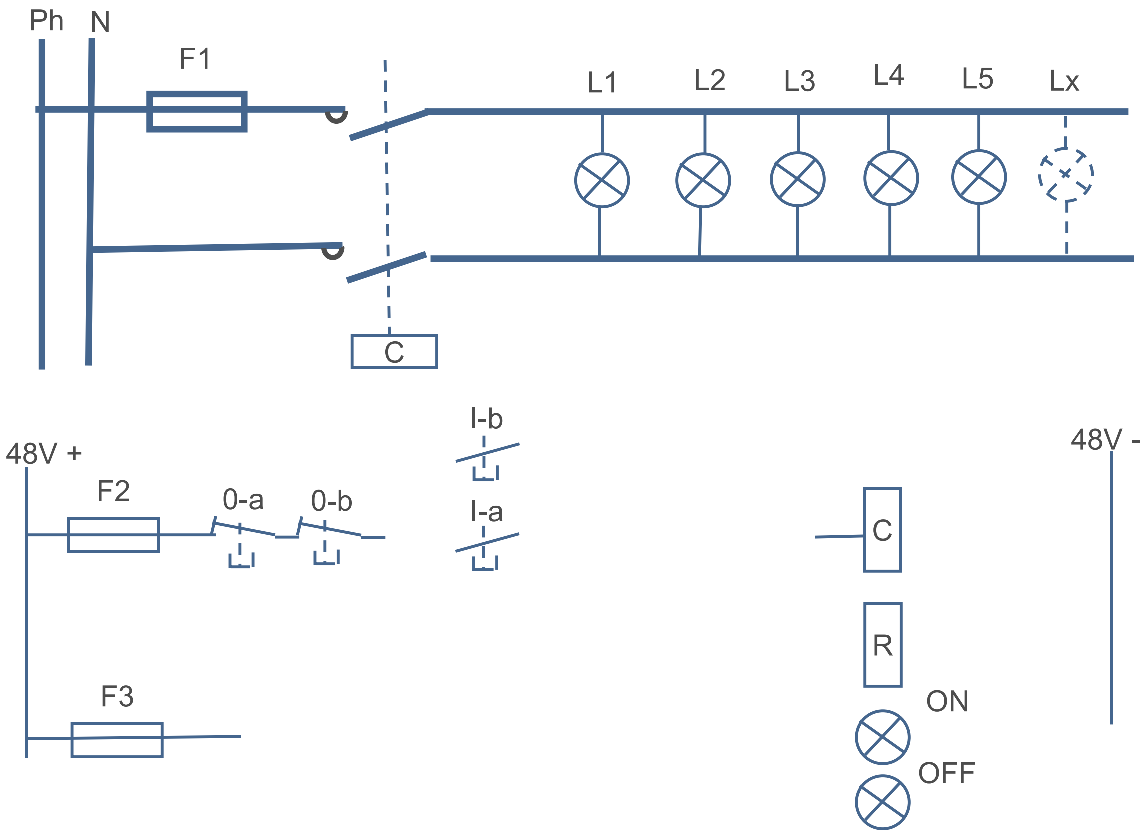
1. One-way motor, with one Run – Stop control panel, with protection thermal relay ‘shunting’ during starting (for a certain time)



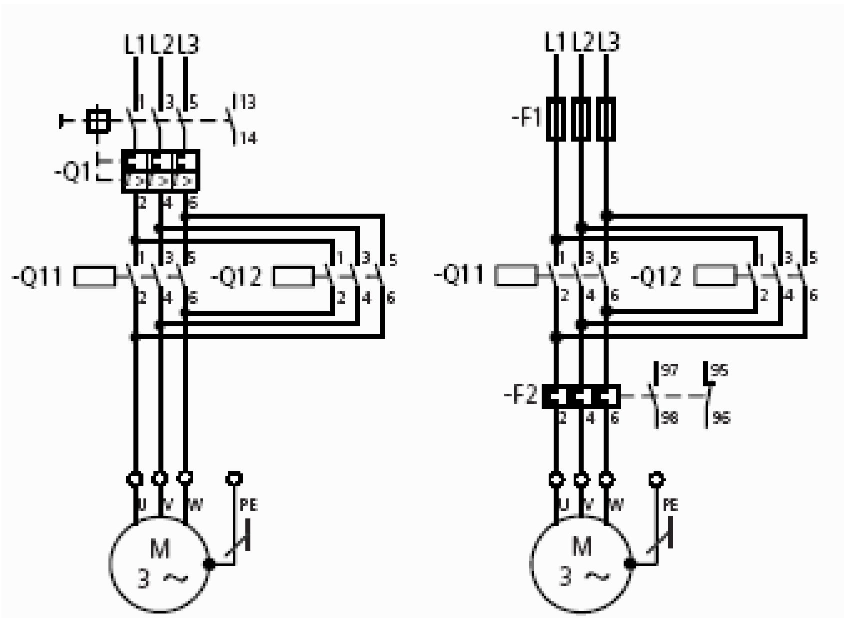
Complete the control circuit

Q14: shunting contactor K1: time-lag relay Q11: line contactor

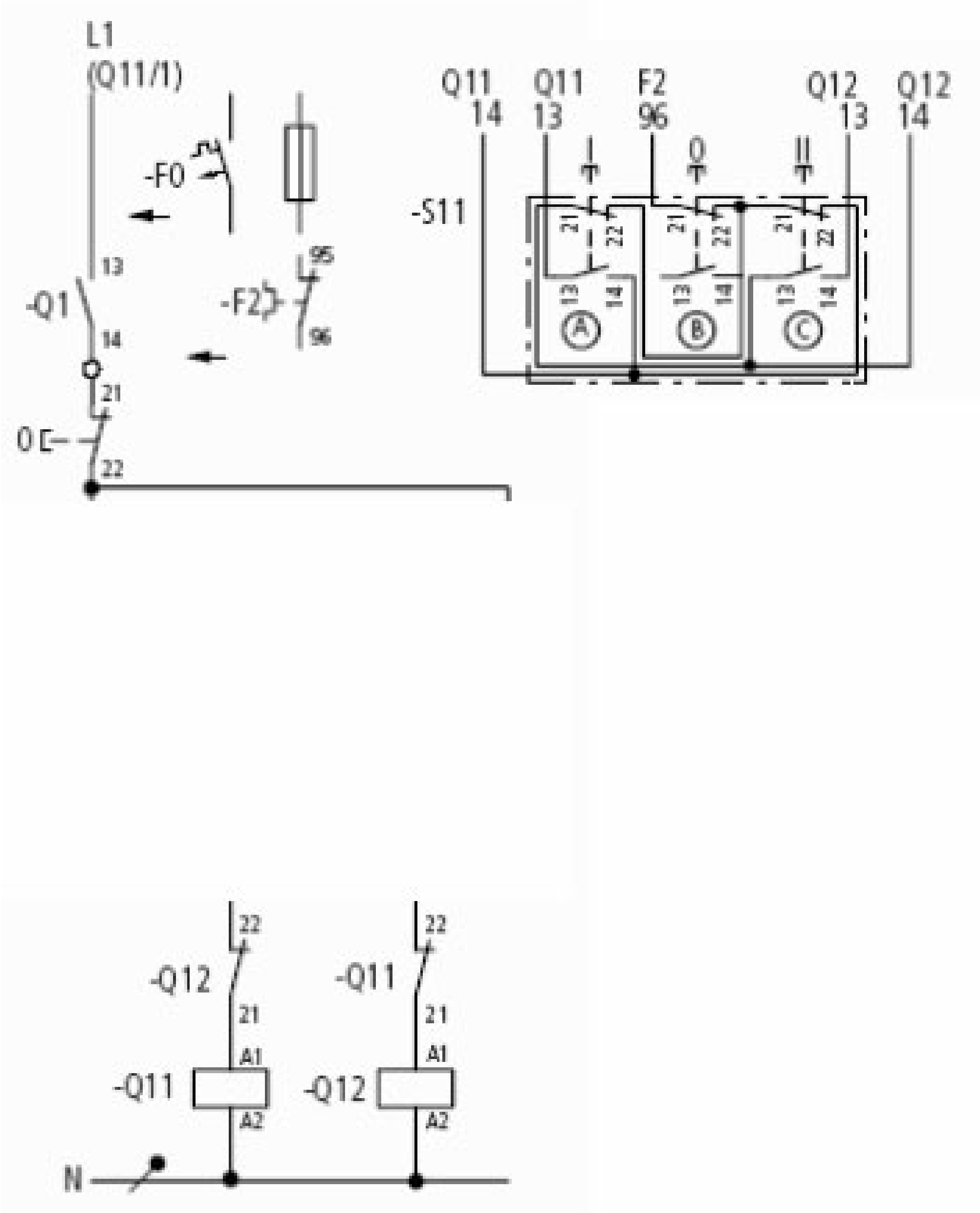
2. Here is a 'lighting' power circuit. Complete the control circuit, if we know that contactor 'C' does not have an auxiliary contact, and self-power supply and indications are handled by 'R', F2 protects the coils and F3 the lamps. *This type of "set-up" is correct*



3. Here are 2 power circuits for the same function, yet they are different. Define both types of starting, 'A' on the left and 'B' on the right. *For the definition, go through the different elements with their functions*



4. Complete the control diagram below



Direction of running reversed ***after* stop button** (button 0) pressed; this control diagram is supplemental to the power diagram above

Q11: line contactor, right-hand running

Q12: line contactor, left-hand running

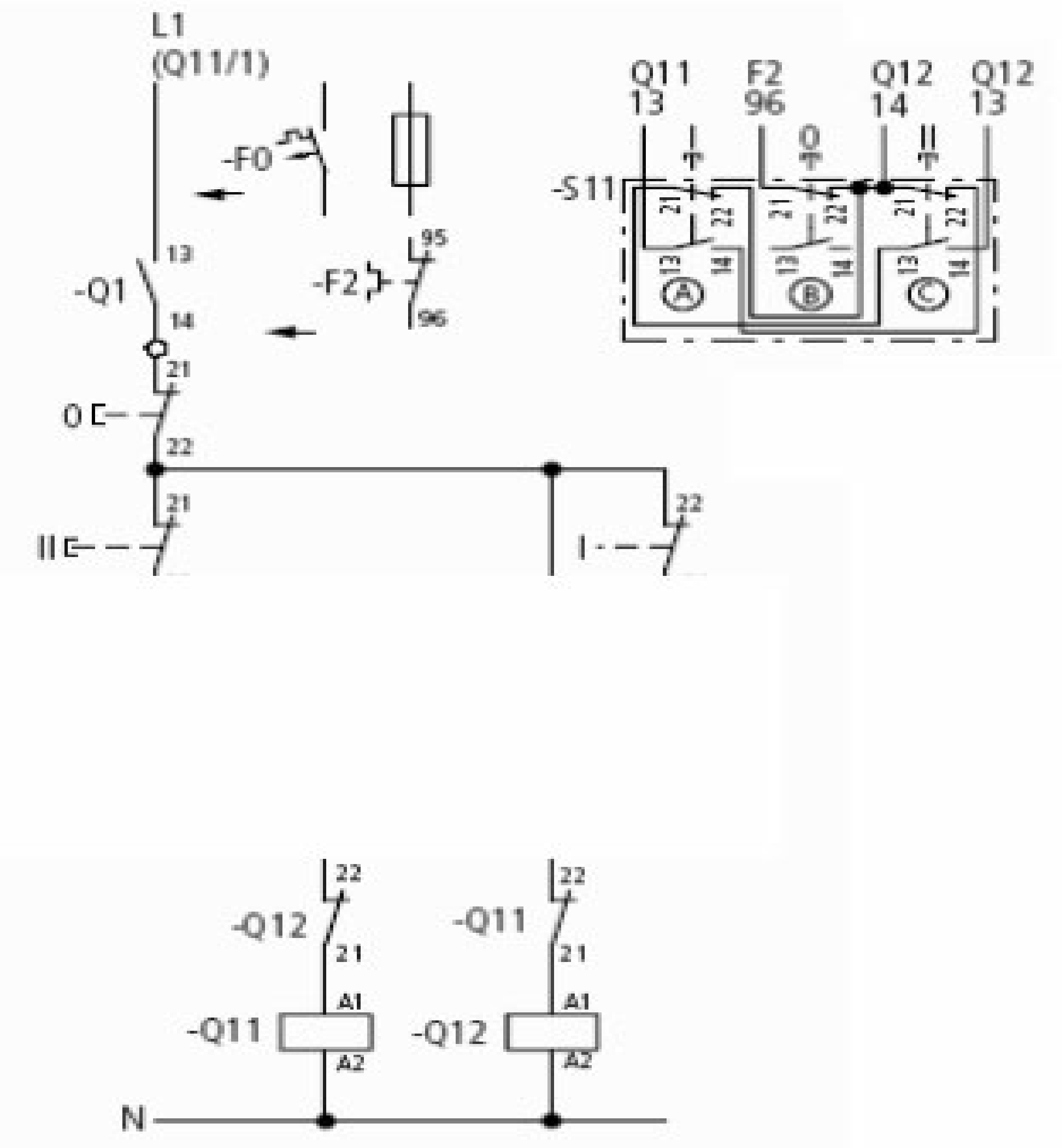
Control panel (S11)

- I = right-hand running
- 0 = stopped
- II = left-hand running

The control panel is represented in wire form to help you; NB we use the run buttons' NO and NC.

The NC contact ‘F2’ is assumed to be incorporated after Q1

5. Complete the control diagram below

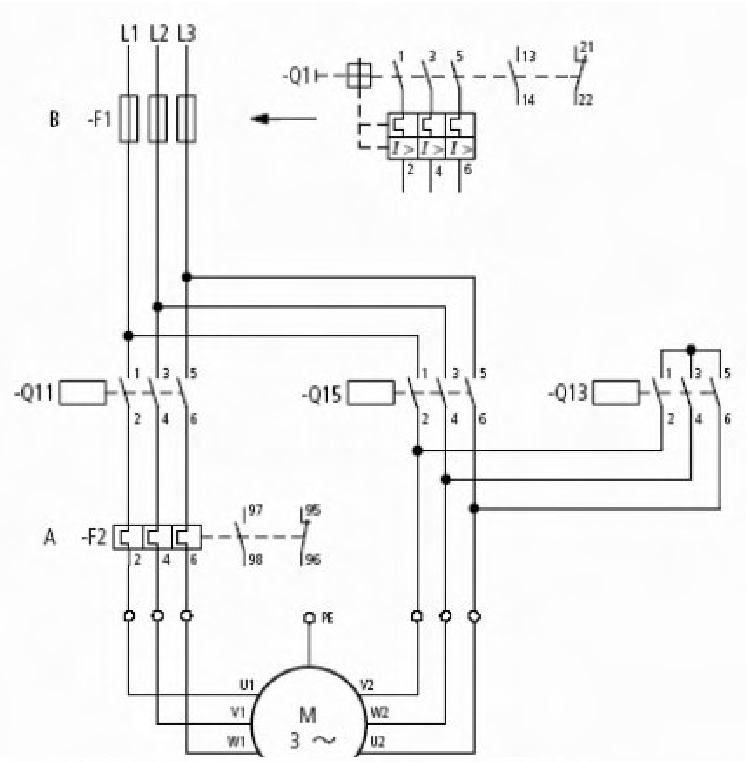


Direction of running reversed ***<u>without</u>* stop button** (button 0) ***being pressed***
Same power diagram as above, with an operating "variant"
Q11: line contactor, right-hand running
Q12: line contactor, left-hand running
Control panel (S11)

- I = right-hand running
- 0 = stop
- II = left-hand running

The control panel is represented in wire form to help you; NB we use the run buttons' NO and NC.
The NC contact 'F2' is assumed to be incorporated after Q1
This looks like the previous exercise, but it is different!

6. Star-triangle starting



The power circuit is shown below. You are already an electrician, and should know what star – triangle starting is
If it is 'hazy', ask for an explanation of the principle of coupling / starting in star and then triangle mode.

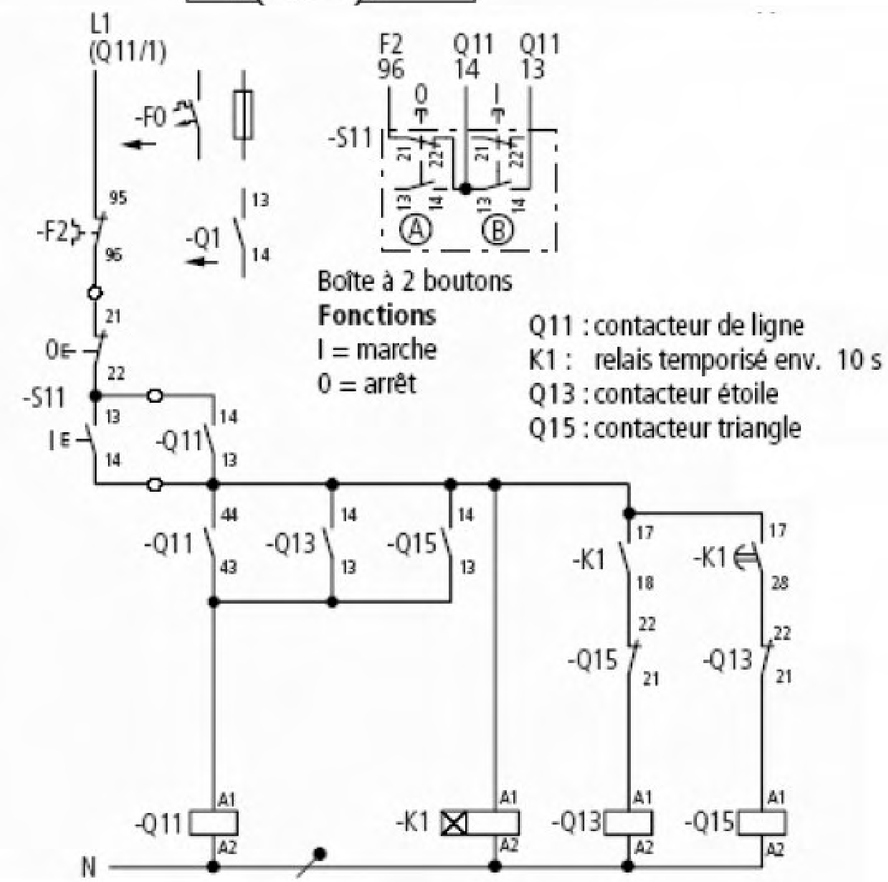
Here the purpose is to work the grey matter to explain a "logic" diagram, involving a schematic of the control circuit

Either fuse or breaker protection

<u>Question</u>: write down the operating steps of the control circuit below, with description of contact openings/closures, and contactor/ relay engagement / disengagement

The first step is:

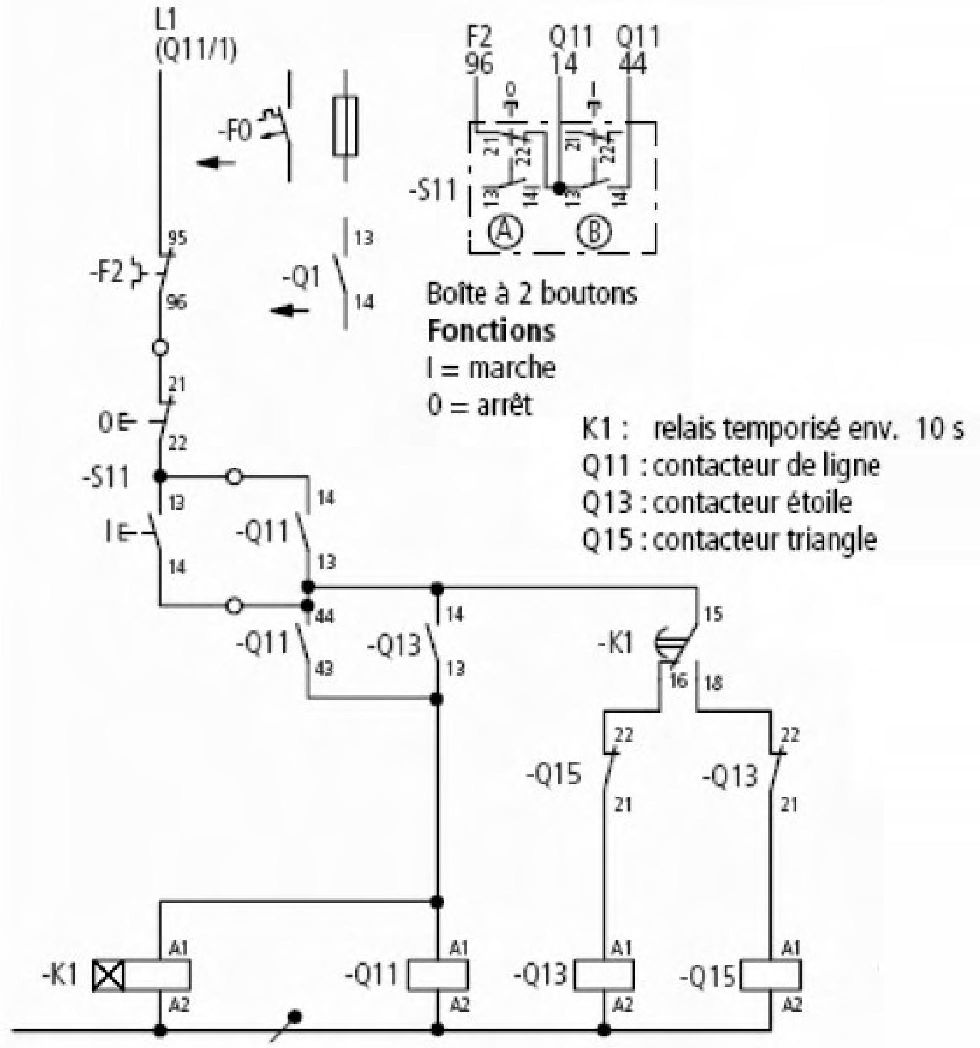
With the system stationary, I press the run button 'I',……..etc.
I.e., what happens



7. Star-triangle starting

The same power circuit as in the previous exercise, but in this case with a second version of the control circuit

Question: note the different operating steps, with all the details required to understand the diagram (descriptive).



In this case too: the system is stationary

- I press the run button 'I'

- The coil on contactor Q13 is excited, and the star coupling is made (power circuit)

- Contact Q13 /13-14 supplies……………etc.

If you are able to describe an automated system sequence, it means that you can read (and understand) a schematic diagram.

5. ONE-LINE DIAGRAMS

A one-line diagram is a simplified representation plan of a multiple-line ***power distribution system*** (*which may combine either: three - phase, three - phases + neutral, one phase + neutral, DC with 2 lines).*

One-line diagrams use just a single line to depict the multiple distribution system drawn in a schematic or wiring and connection diagram. As it is a simplification, it is clearly easier to read, and combines on the same plan as many circuits as possible, with the aim of getting an overview of the installation / electric distribution of the unit in question.

Under the more “official” definition of NF X 50-106-2: it is a diagram providing the configuration of electric networks, including those of automated systems serving the various parts of a unit, showing their inter-relations and the hardware used to this end.

5.1. PRINCIPLES – ONE-LINE REPRESENTATION

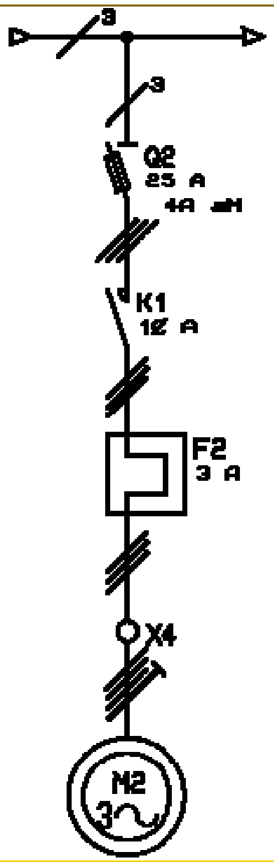
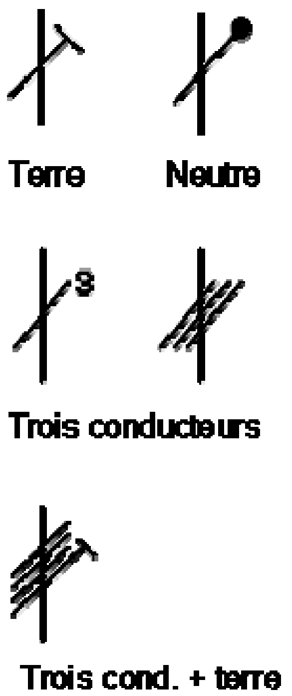
Example of a one-line diagram	Symbols used for one-line representation:
	

Table 1: Representation and symbols for wiring in one-line diagram

- Two or more conductors are represented by a **single line**.
- On this line we indicate the number of conductors in parallel.
- This representation is mainly used in three-phase distribution, this being the most frequent and common distribution. But a one-line diagram can cover several different types of distribution on the same page (three and single-phase, DC, etc.)
- The symbols for multi-pole devices are strictly the same as those used in other types of diagram – in 1 pole representation (obviously).
- One-line diagrams indicate the "electric relations" between the various elements / components of an installation (rather than the physical relations of positioning for example).
- One-line diagrams combine and provide a great deal of information

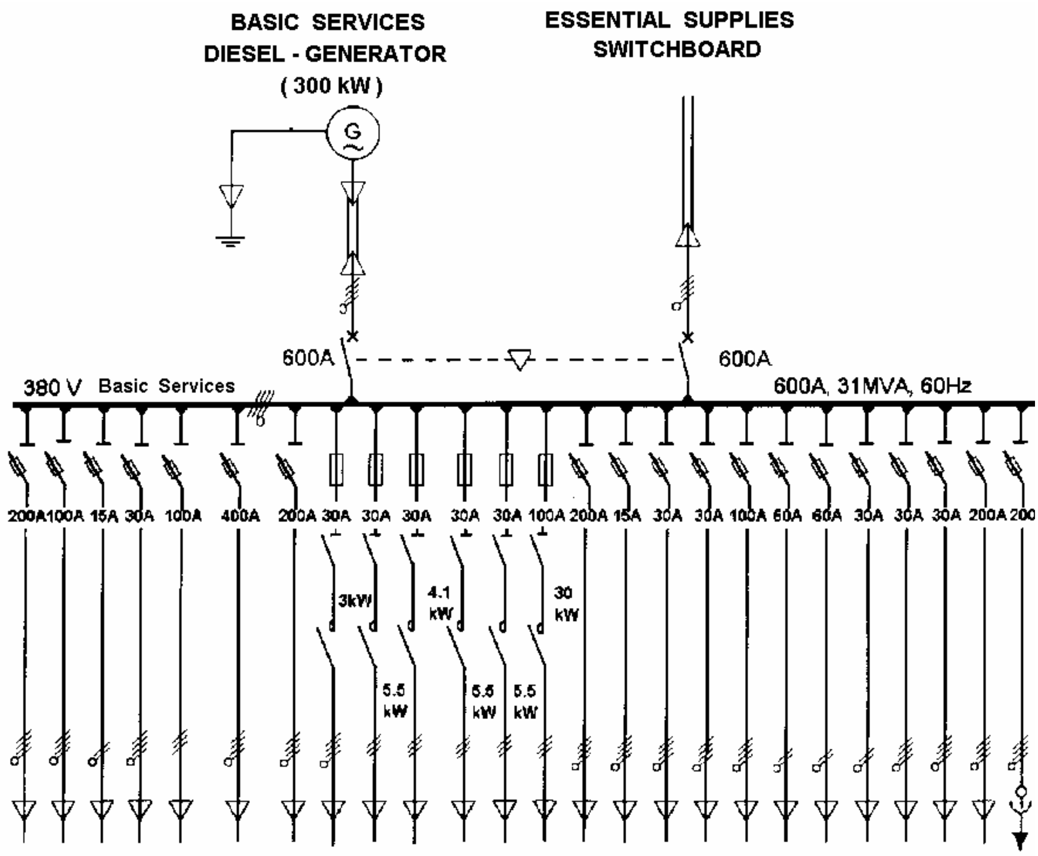


Figure 12: Example of one-line diagram

One-line diagrams on site are (nearly always) in A0 and A1 format. It's rather difficult to switch that to A4 format. For the course, try to obtain a "real" one-line diagram, and you will see that it provides a great deal.

When we want a schematic representation of a distribution system "principle", we use the one-wire system. In the example below, the symbols are not complete, as the aim is simply to provide an understanding of the use of the various distribution networks with a one-line "sketch".

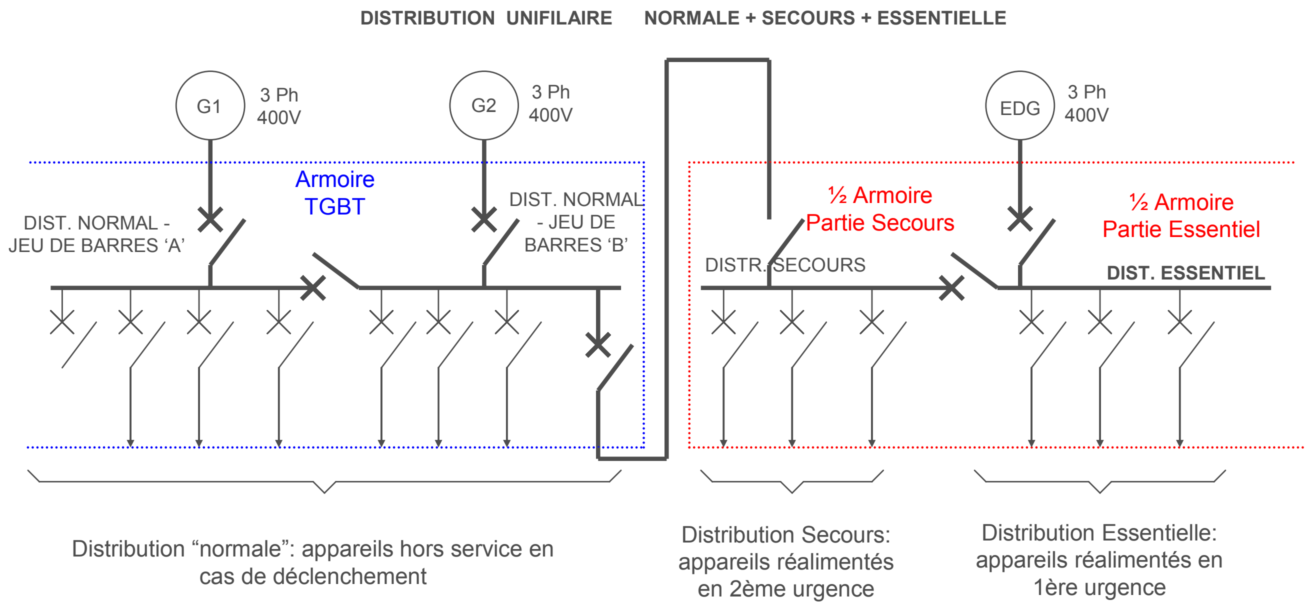


Figure 13: One-line sketch

Example of site diagram:

The example below is a copy of a one-line diagram of the distribution system on Total Indonesia's CPU site.

It shows the HV (or MV for Medium* Voltage) distribution loops at 3x5.5 kV, and the LV distribution principle (LV for Low voltage) at 3x400 V

* *MV no longer officially exists: LV denotes up to 1 kV, and HV systematically denotes voltages above 1000 V.*

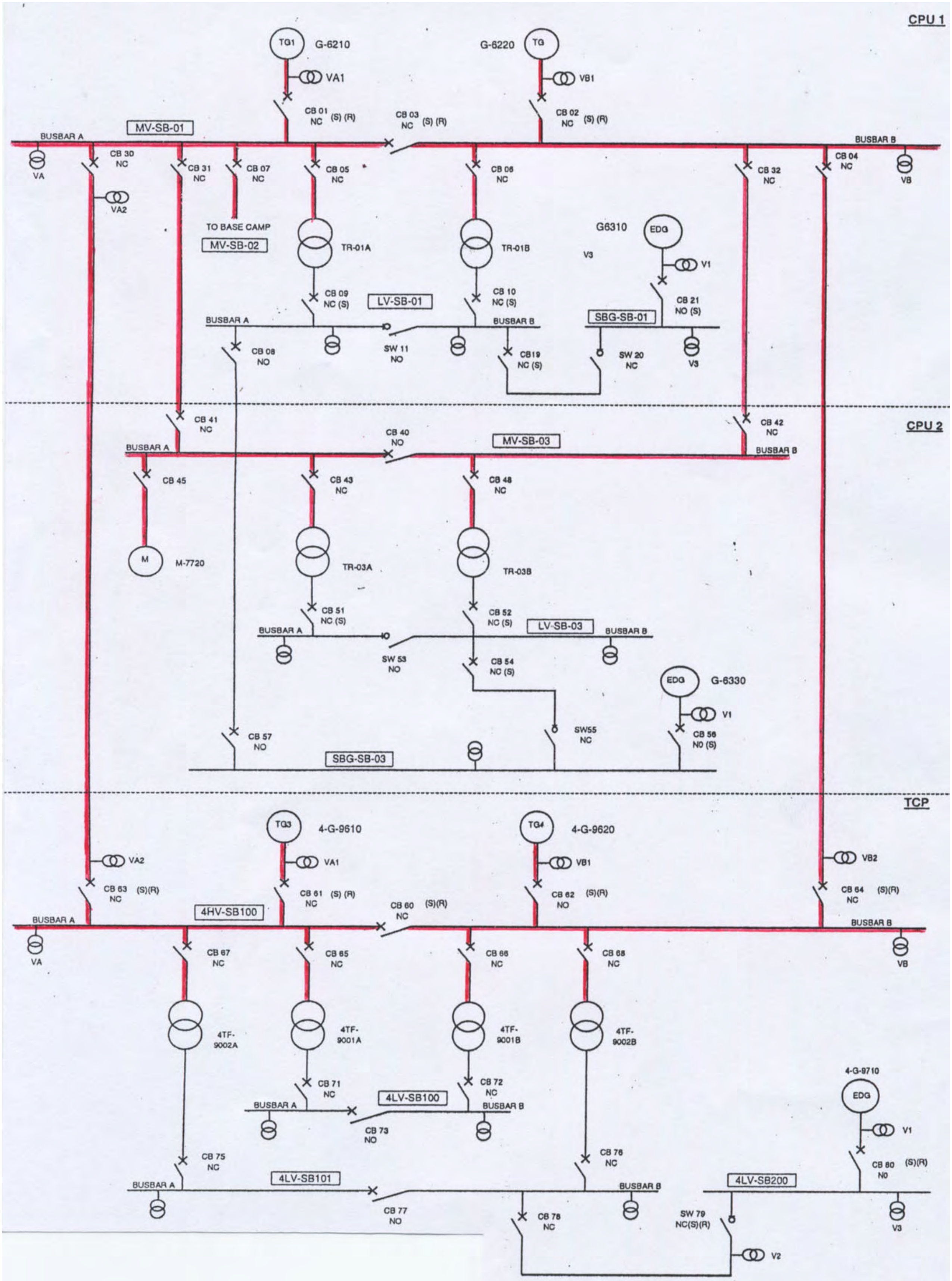
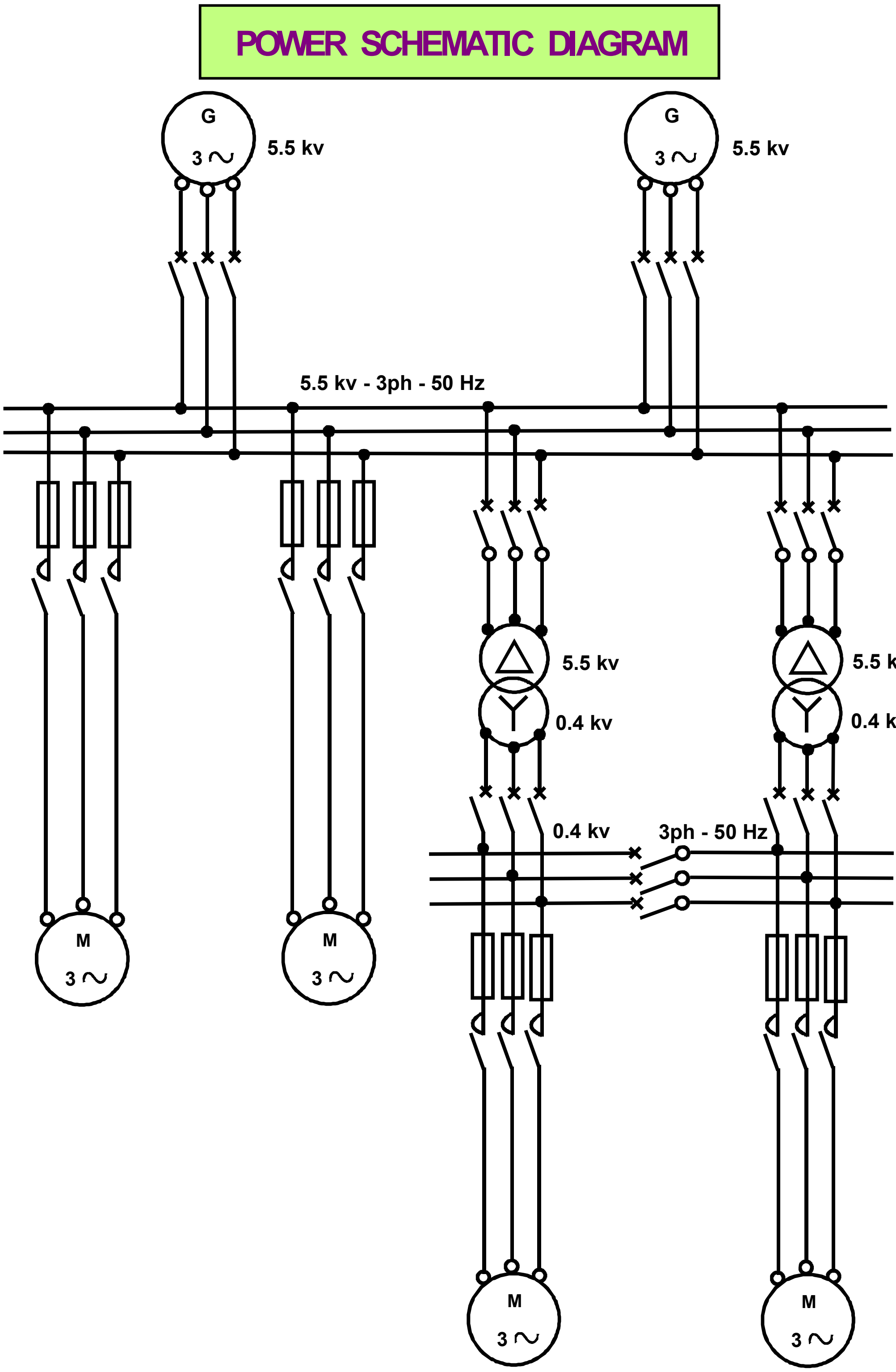


Figure 14: Example of one-line diagram (Total Indonesia – CPU)

5.2. ONE-LINE DIAGRAM EXERCISE

8. Draw the one-line equivalent of the diagram below



6. BLOCK DIAGRAM

What if we don't have the time to draw a schematic diagram or even a one-line diagram, if we just want to explain how a piece of equipment, system or installation works without aiming to indicate the "frills" of characteristics, symbols, standardisation, etc.?

In this case we use boxes, saying what they are with text inside them, and put arrows between them, with arrows and boxes - but in a logical, functional order!

6.1. BLOCK DIAGRAM – FUNCTIONAL CHAIN

6.1.1. Definition

A functional chain represents an elementary unit in design and investigation of automated systems. It is characterised by functional arrangement of constituents in the form of a chain, which combines all the elements of the Control Part (CP) and Operative Part (OP) involved in performing an operative task. (see GRAFCET section)

6.1.2. Modelling a functional chain with a block diagram

6.1.2.1. Construction rules

Each block represents a constituent in the chain, and may have two meanings:

- in terms of **constituents** (sensor, pre-actuator, …),
- in terms of **automated functions** (acquiring and transmitting, distributing energy, …).

Each link represents a relation between two blocks, and shows the information and/or physical quantity exchanged between the two constituents. A link may also have two meanings:

- topographic (physical link needed for signal exchange. Examples: electric wire, conduit, etc.).
- functional (nature and direction of exchange. Example: sensor sends a report to the PLC input module).

AN ACTUATOR HAS A CORRESPONDING FUNCTIONAL CHAIN

For functional chains with an actuator performing two actions (Examples: double action ram, two-way motor, etc.), it is recommended for detailed modelling to use two block diagrams (one for each action).

6.1.2.2. Properties of a functional chain

A functional chain generally comprises three parts:

- **energy chain**,
- **information chain**,
- processing chain.

6.1.2.3. Mnemonics used for block diagram modelling

For energy flows:

WP.C: control part supply energy

Wcp: power control energy

WS: stored power energy

Wdis: distributed power energy

Wadap: adapted power energy

WR: residual energy

WEnt : PLC input energy.

For material flows:

MOe: input flow

MOs: output flow

6.1.3. Representation of a functional chain

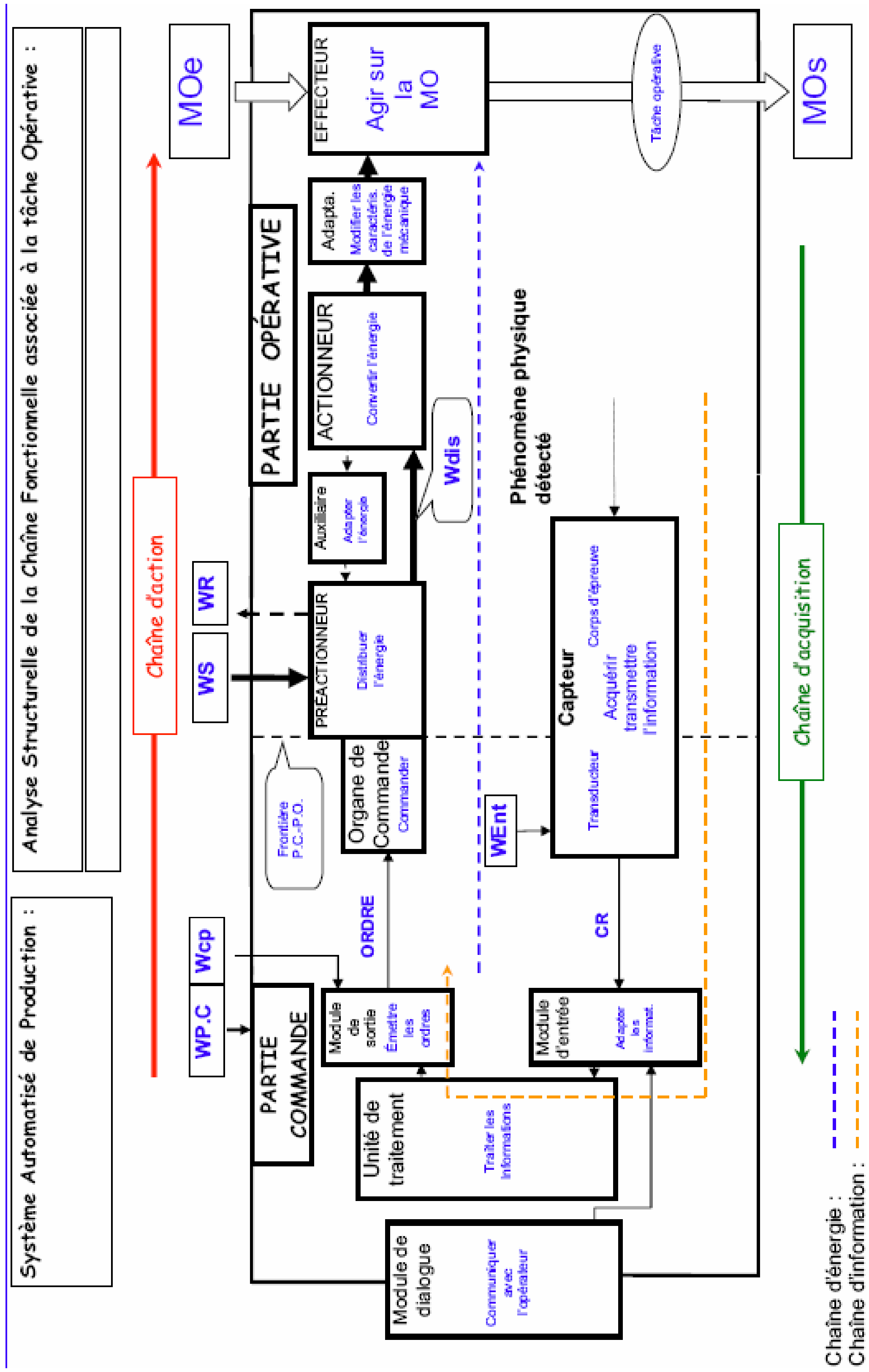


Figure 15: General representation of a functional chain

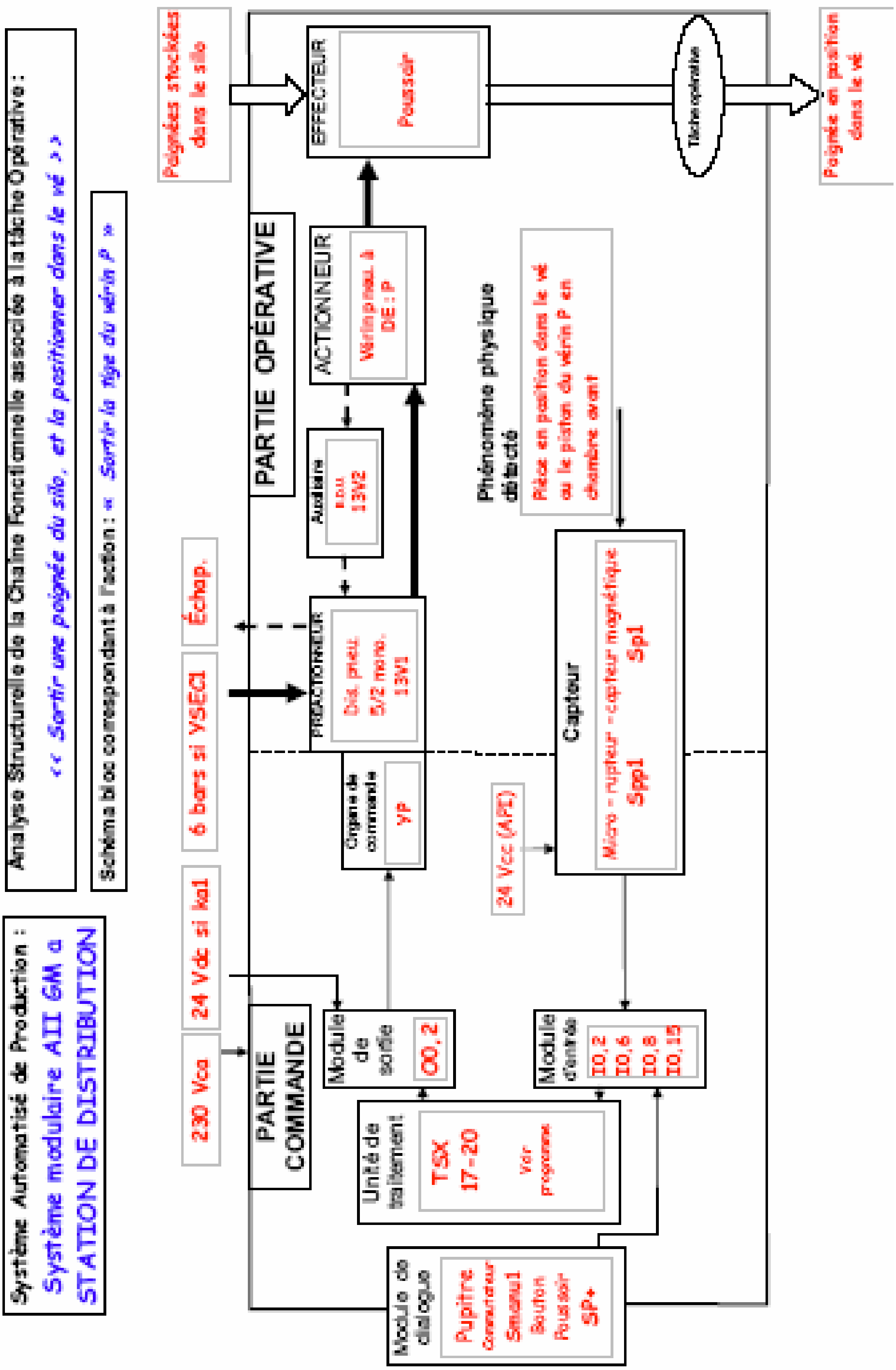


Figure 16: Example of a functional chain as a block diagram

6.2. BLOCK DIAGRAM – FUNCTION LOGIC

A block diagram may apply to any logic sequence of events employing various elements / components not just in the technical fields of electricity, instrumentation, mechanics, process, etc., but anywhere!

Here we will concentrate on the field of electricity, taking our examples from this field of activity.

NB – we have not got to logic blocks ('and', 'or', 'nand' functions, etc.) assembled in blocks to form a diagram…, that is covered in a later section.
It's rather mixed up as an explanation, but I can't see a better way of doing it – in any case, below you will see where our focus lies.

Block diagrams describe a function (or several functions) and/or events between input and output variables. These variables are connected to intermediate blocks by connection lines, and one block output can be connected to the next block's input (or more than one block). The connections are oriented (generally from left to right and top to bottom), and may be branched
All lines and arrows must be identical.

Example of an inverter's block diagram

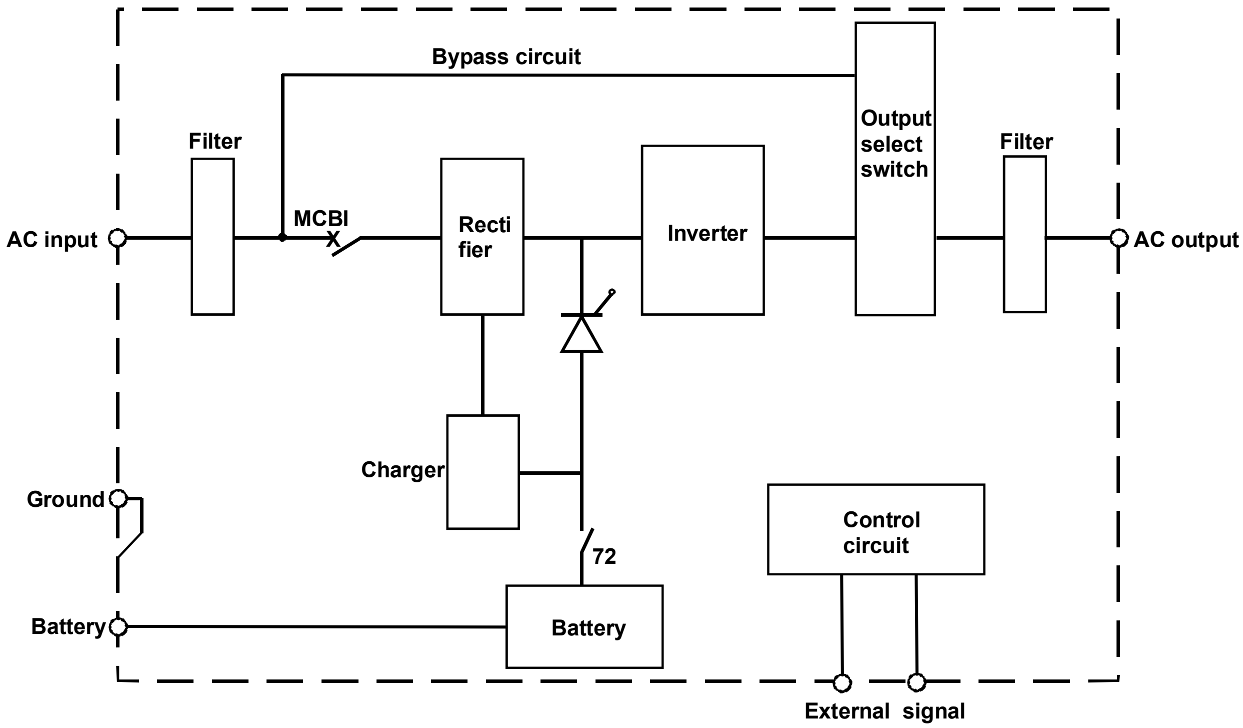
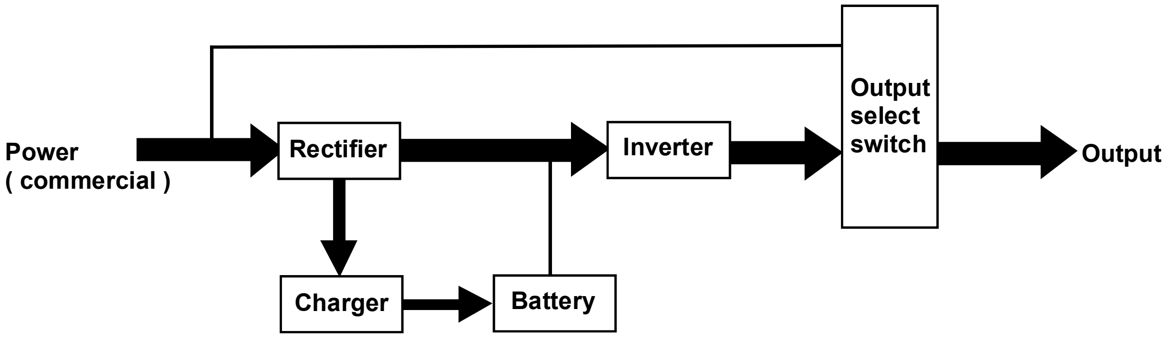


Figure 17: Block diagram of an inverter

And based on this block diagram, operation under a variety of configurations may be represented.

Operation under normal conditions (a):



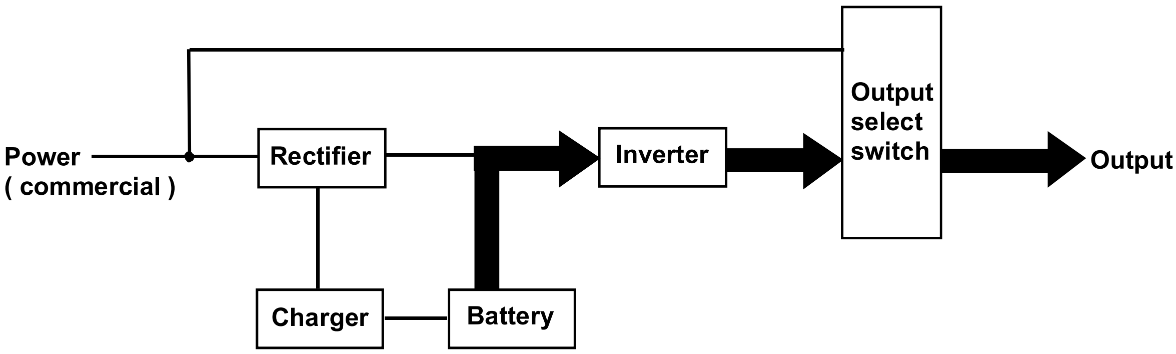
(a) NORMAL POWER SUPPLY ROUTE

Figure 18: Inverter in normal operation

This inverter receives energy from the 'normal' distribution network, converts it into DC energy with the rectifier block, and reconverts it into 'AC' energy (with the inverter) which is synchronised with the initial source at the output to supply the safeguard network.

The battery is kept permanently charged (floating) to be ready to come on in case of failure of the normal power source (unit shutdown, voltage drop, etc.).

Operation in event of normal power loss (b):



(b) POWER SUPPLY ROUTE WHEN COMMERCIAL POWER SUPPLY IS ABNORMAL

Figure 19: Inverter in operation with battery

When the normal source is 'down', the rectifier and charger can no longer operate, but the inverter continues in 'normal' operation, taking energy from the batteries, and continues to supply the load without interruption, with the battery 'floating'. *This system is also known as a UPS, or Uninterrupted Power Supply.*

Return of normal power (c):

Once 'normal current' returns, the rectifier and charger start up again and restore the "normal" supply to the inverter block automatically, and still without interruption. Operation returns to the first configuration (a).

When it returns to 'normal', the charger will have an additional function, recharging the set of batteries to maximum charge (floating mode). The rectifier / charger assembly must be set up accordingly, and have a double capacity.

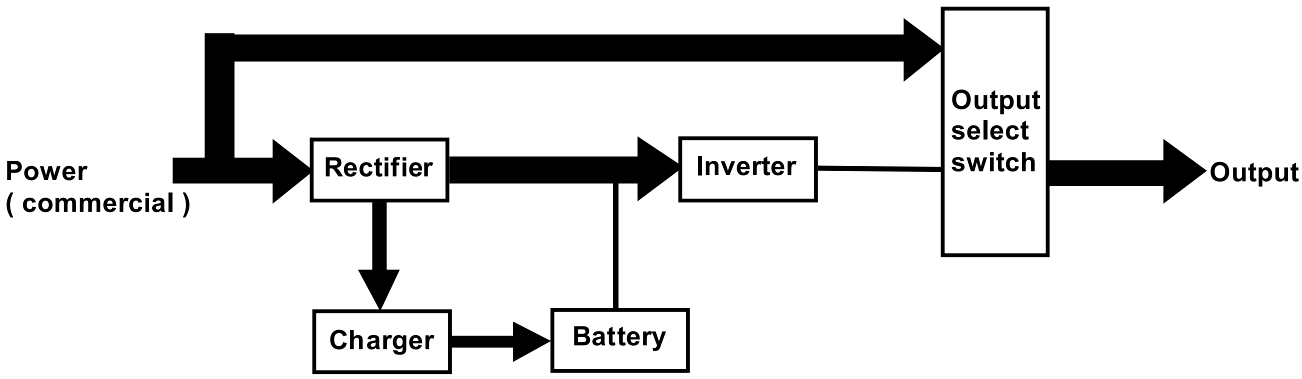
The normal source is down for a long period (d):

If the restoration of normal voltage takes some time, the battery will be drained and reach the low voltage critical threshold. The protectors are activated to stop the inverter, to avoid damage to the battery.

So this consequence is complete shutdown; which is why on the sites, it is better to restart at least the back-up units to restore the supply to the "essential" circuits under normal current as quickly as possible. Inverters are (always) connected to the essential circuits.

When normal supply is restored, the entire rectifier / charger / inverter assembly returns to normal function automatically, back to condition (a).

Inverter problem (e):



(e) POWER SUPPLY ROUTE WHEN OVERLOAD APPEARS OR WHEN INVERTER FAILS

Figure 20: Inverter in by-pass mode

In the event of an inverter problem (overload, component failure, etc.), the static or select switch automatically switches to 'normal' source, without interruption.

If the inverter returns to service, generally we need to reactivate the inverter from the cabinet to restore condition (a).

7. EARTHING DISTRIBUTION DIAGRAMS

This section is not about the various methods of earthing (which is covered in the specific course "earthing"), but only about the earthing cable installation plans (foundation earth), and the various connections to metal earths (plans showing the connections in detail).

7.1. GENERAL EARTHING DISTRIBUTION DIAGRAM

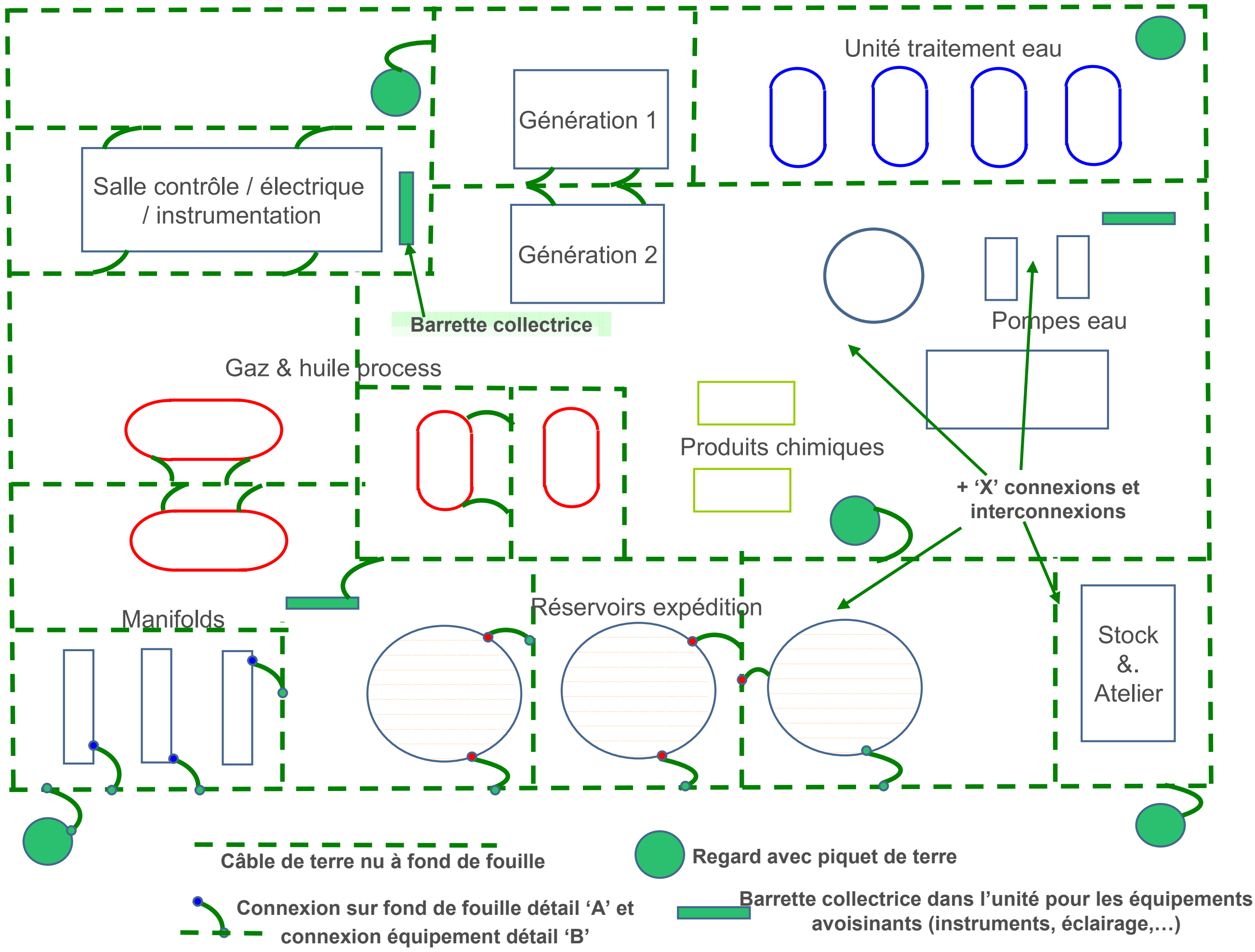


Figure 21: Earthing distribution schematic and unit connections

Diagrams of this type can combine 'x' pages covering distribution and details with layout plans of equipment on-site, units, sub-units, sub-assemblies, etc., according to the size of the site.

This is a type of one-line diagram showing on an equipment layout plan:

- All the bare foundation earthing cables (buried), with the cross-sections indicated
- All overhead bare earth cables (on cable runs or in conduits), with the cross-sections indicated
- The connections of this general earthing distribution system (foundation and overhead), with the electric equipment, showing connection details or containing a reference to a detail book defining the connection type.

- Connections with metal ‘process’ equipment (with or without electric hardware on equipment) (with detail reference)
- Connections with metal structures (with detail reference)
- Connection details and methods on general plan and/or in an associated book between the foundation earth and connected metal equipment
- Earth pits and earthing rods, with connection details
- Earth collection bars, cut-out bars/strips
- Interconnections with other specific earth networks (instrumentation, electronics, lightning, etc.
- …/…

7.2. EARTHING CONNECTION DETAILS:

In addition to the general distribution diagram, there is a book for each project showing details of the connection principles and methods. It indicates specifically the type of hardware to use, and how to install all the connections.

This will be: bypass from the foundation loop (with connector or welded), connection to a structural pillar (welded, screwed, bolted, etc.), how many connection points on a tank, how it connects to the earth collector, etc.

Total's General Specifications provide these details, but every project and every site has its own detail book *(very often hard to find once construction s complete…)*

Example of connection details

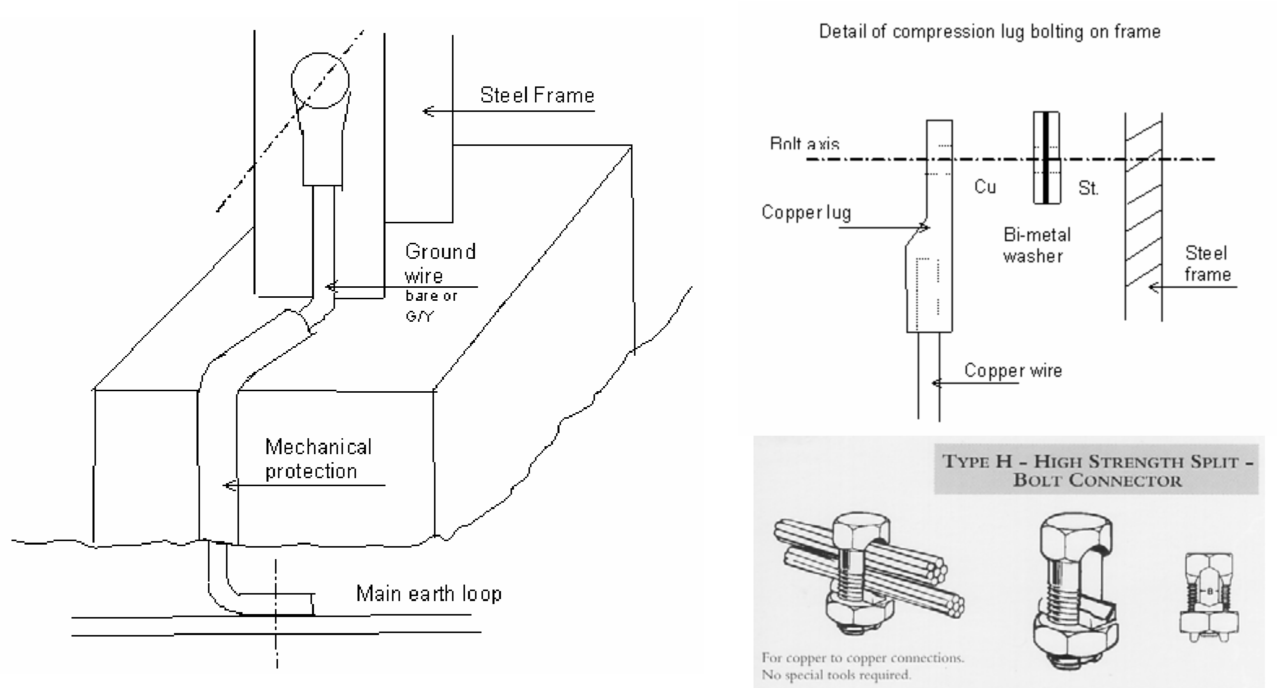


Figure 22: Examples of earth connections on metal structure

Note: connections to foundation earthing generally use the thermit welding system. This same process is used for connections to metal structures.

Two different metals in association create between them a galvanic couple causing corrosion. The welding process melts the metals, agglomerates them and eliminates this couple phenomenon

In the example above, with a copper foundation cable connection to a steel structure, if we do not use the weld, we are forced to use a bimetal (Cu – steel) 'interface', already melted together in contact

The principle of thermit welding is covered in the course "earthing and electrical faults"

Earthing rods

In the connection details you will find information on earthing rods, for on-shore installations (naturally).

You will also have technical information in the form of datasheets, with sizing and also the connection method.

Earthing rods always have an earth inspection hole, which is indicated on the earthing distribution diagram

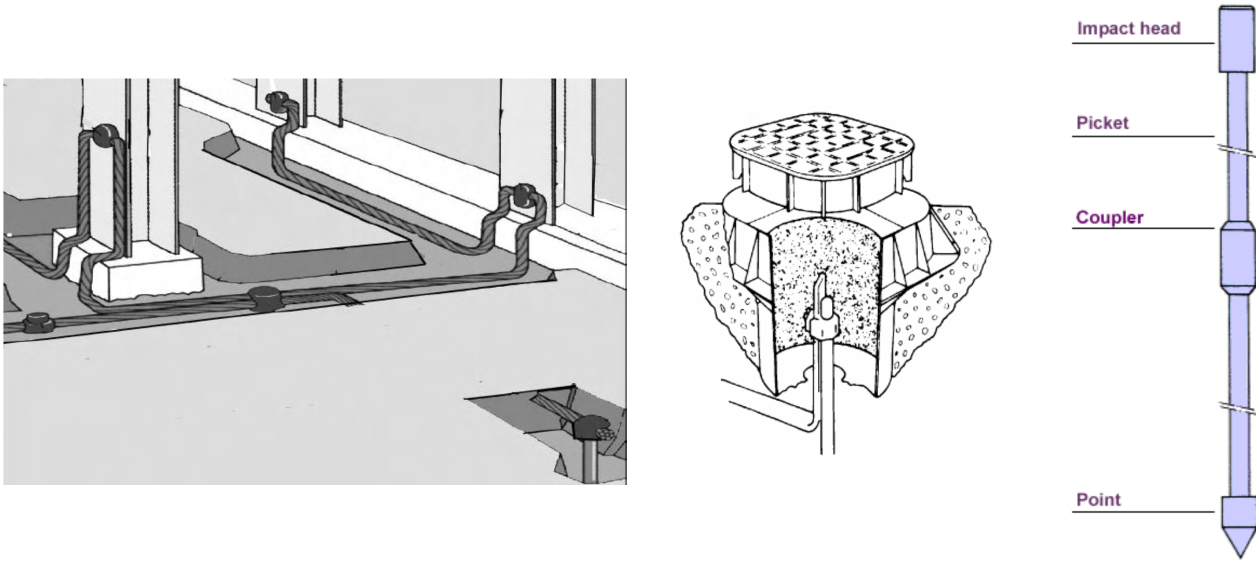


Figure 23: Earthing pit, inspection hole and welds on structure

This type of detail is included in the diagrams supplementing the earthing distribution. Your site will have them; they are an integral part of the ‘project’ documents. I stress this because of the number of times I have seen earthing connections "neglected" and heard comments such as "we don't have any plans, we don't know how to do it".

If you have a position of responsibility (in electricity) on your site, find these plans, keep them permanently available and show them to your subordinates so that they never forget to connect the earthing ***properly***

7.3. EARTH LOOPS

We will examine this theme during the specific earthing course; here we will simply take a look at 2 "little things" that it is probably better to know right now…..

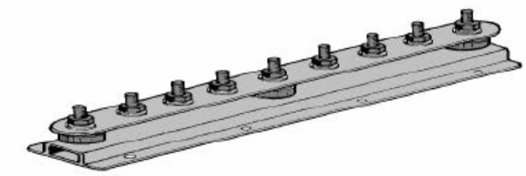


Figure 24: Earth collector

All earth cables connected to equipment, and foundation earth loops, will be (sooner or later) connected to a collector, a "clustering" bar.

There are several bars fitted in the unit, with a general collecting bar on the low voltage master switchboard, or the power generation unit. An overall measurement of the earth value is taken at the central point; a value which must be as follows:

- ***For our On-shore units:***

  < 10 ohms (under 10 Ω) in areas classified as no-risk; in practice the value obtained is even most often below 2 ohms

  < 1 ohm (under 1 Ω) in areas classified as at-risk (0, 1 and 2 – for installation of hardware, E.g. ATEX)

- ***For our Offshore units:***

  < 0.5 ohm (under 0.5 Ω) at any point of the installation

7.3.1. "Electrical" ground and "mechanical" ground

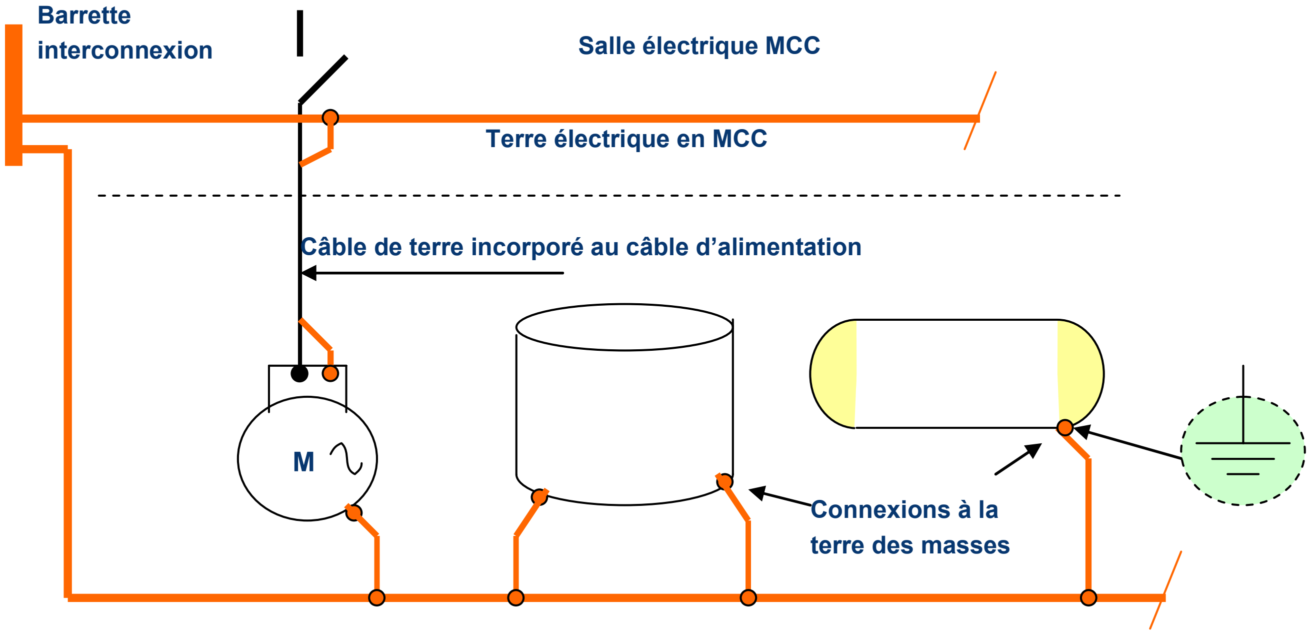


Figure 25: "Electrical" ground and "mechanical" ground

There is no 'specific' term to distinguish the types of ground connection. The terms "electrical" and "mechanical" have been invented for ease of comprehension here, so that you know that on an industrial site:

- An **electrical device** (motor, light, heater, …) ***is connected at least twice over*** to earth; to "mechanical" ground (earthing of masses, on-site loop), and to "electrical" ground via its supply cable, which will obligatorily have a 'PE' conductor, the 'green - yellow' wire.

- A **metal mass,** even without any electrical equipment (tank, separator, skid, etc.) ***has at least one connection*** to "mechanical" ground. There may be more than one "mechanical" connection; this depends on the mass itself (the volume of metal); you need to look up the regulations / standards to find out these details.

"Electrical" and "mechanical" grounds are combined on a general collector.

Some more advice for you: on "your site", if you see "mechanical" grounds not connected or even incorrectly connected, and you think that it ‘is not your concern’, you should know that you are actively contributing to the corrosion of the equipment and that you will bear part of the responsibility for a future accident due to an electrical fault….

7.3.2. Domestic distribution

At home, it is essential to connect all the metal parts; below is a diagram which is not "standardised", but which at least has the merit of being ‘explicit’.

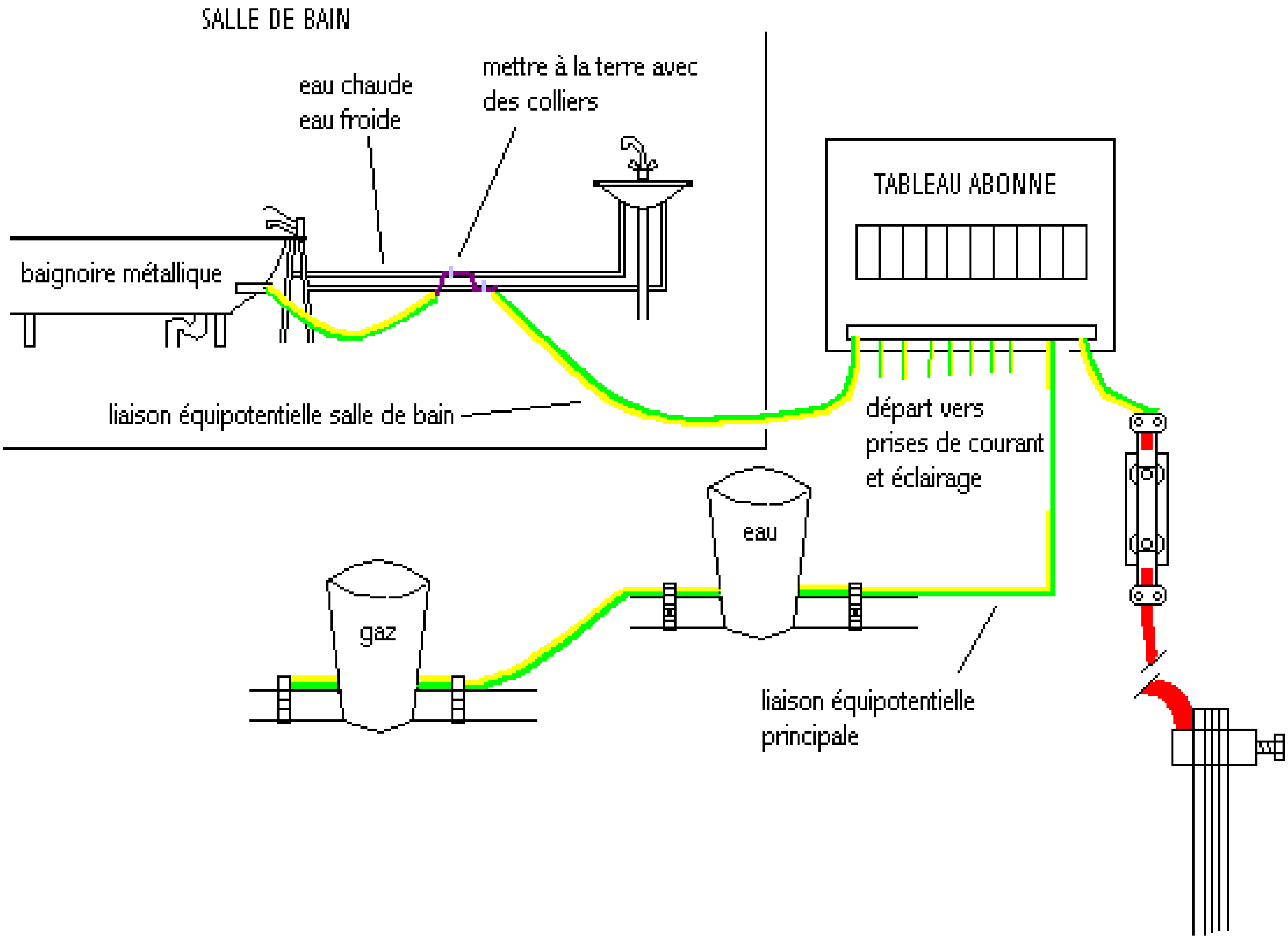


Figure 26: Inter-connection between grounds in domestic distribution

8. LOGIC DIAGRAMS

We are now entering the “digital” field.

If to indicate a physical quantity, such as the number of volts, we use an ‘analogue’ voltmeter, the reading is indicated by a needle on a ‘physical’ scale, or the reader has to make their own value estimate

With a ‘digital’ voltmeter, the numbers appear directly. So a coding system, a ‘digital’ system is required in order to convert a physical quantity into a numeric (or digital) display.

This brings us to the ***‘0’ & ‘1’ system***

8.1. COMBINATORY LOGIC

Before we look at some Boolean algebra, binary code, truth tables, logic symbols (and gates), let's first see how it all blends together in terms of "logic".

8.1.1. Binary variables

Electrical engineering, electronics and mechanics study and apply the variation of physical quantities such as pressure, level, voltage...

Certain applications that only consider **two values** relative to these physical quantities means that these are considered as **binary variables**.

8.1.2. Logic states

The two values that can be adopted by a binary variable define, in particular, its two logic states, which are expressed by means of symbols for which the numbers **0** and **1** are conventionally used.

8.1.3. Logic function description tools

The logic function performed by a binary operator can always be defined by a literal expression.

Example: *the lamp is at state 1 (lit) if, and only if, the switch is in state 1 (closed).*

This literal expression may have other associated modes of representation:

- Logic symbol,

- Contacts diagram,
- truth table,
- chronogram,
- and logic equation.

8.1.3.1. Logic symbol:

This is the standardised schematic representation of the operator.

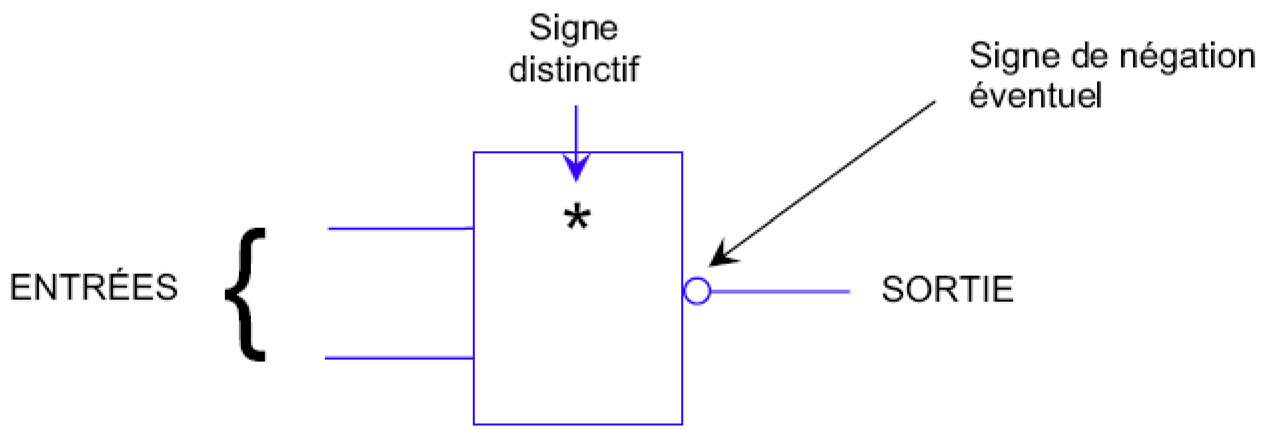


Figure 27: Representation of logic symbol

Under standard (NF C 03.212), the representative symbol of a logic operator comprises a rectangle, the upper third of which contains one of the following distinct signs: **1**, **&**, **≥1**, **=1**.

The operator input(s) is/are generally on the left, with the output on the right.

The **o** sign that may figure at the output indicates negation of its logic.

8.1.3.2. Contacts diagram

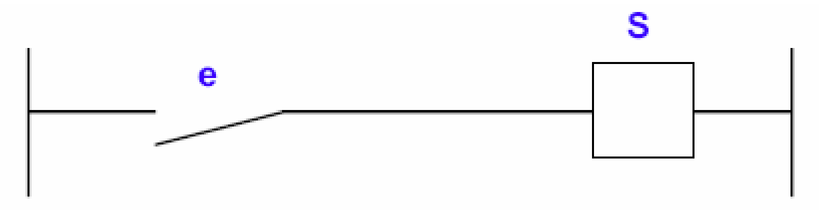


Figure 28: Stylised representation of contacts diagram

**Le contact concrétise, par ses deux positions,
les deux états d'une variable binaire d'entrée.**

Le contact* e *est la variable d'entrée.
S est la variable de sortie.

8.1.3.3. Truth table

For combinatory logic binary operators in which a combination of input variable states has only one corresponding output state, the truth table specified all possible relations between these states.

a	b	S
0	0	0
0	1	0
1	0	0
1	1	1

Figure 29: Truth table with two input variables:

Pour calculer le nombre de combinaisons à inscrire dans la table de vérité, on peut utiliser la formule suivante
Nb. Ce combinaisons = 2^n
(2 représente le nombre d'états logiques possibles et n le nombre de variables d'entrées).

8.1.3.4. Chronogram

A chronogram is a graphic representation displaying all possible combinations of input logic states the corresponding output state, as a function of time.

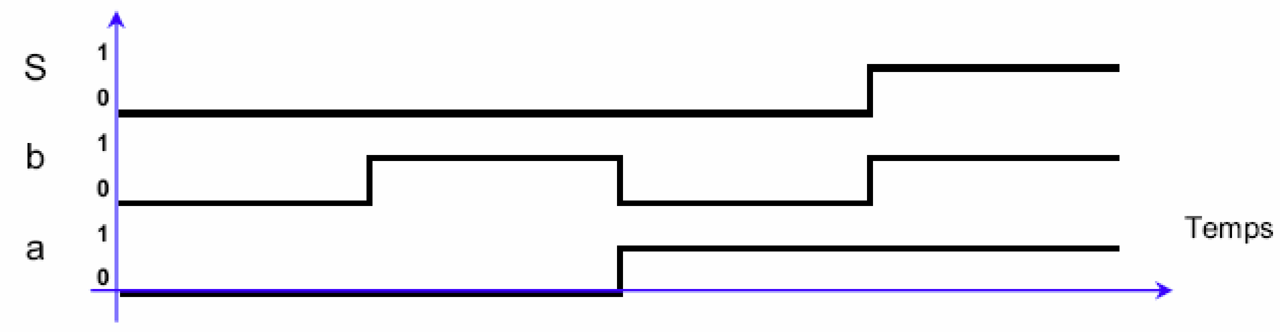


Figure 30: Chronogram in logic representation

8.1.3.5. Logic equation

L'équation logique traduit, selon les règles de l'algèbre de Boole (*), la relation qui lie entre elles variables de sortie et variables d'entrée.

(*) *George BOOLE (1815-1864) was an English mathematician who codified logic operations and functions. This has proved to be an essential tool in computing.*

The **=** sign denotes equality of state between the two members of the equation.
In each member the variables may be associated for the following operations:

- logic product, **AND**, by the symbols **x**, **.**, which are read as **AND**,
- logic sum, **OR**, by the symbol **+** which is read as **OR**,
- logic negation, **NOT**, by the symbol **-** which is read as **NOT**.

$S = a \times b = a \bullet b = ab$

Ces trois expressions identiques se lisent : S égale a ET b.

8.1.4. Logic diagram

Logic processing of information may require the use of a large number of binary operators, which need to be interconnected.

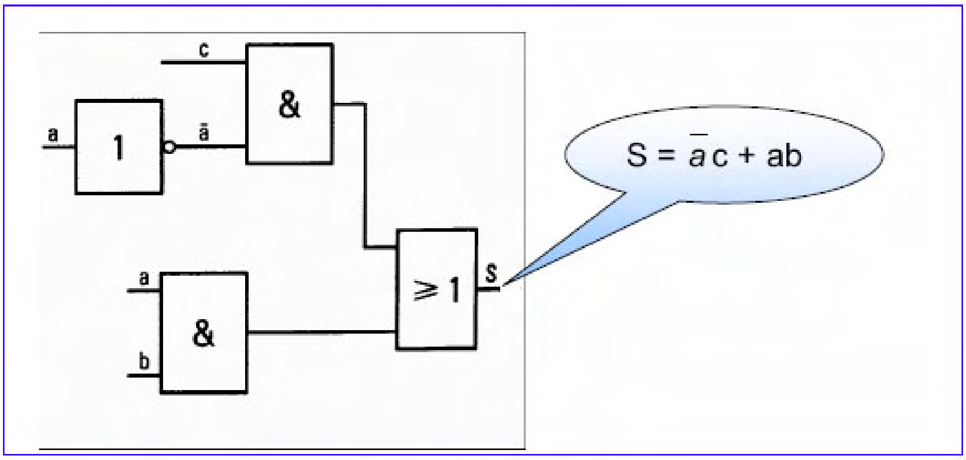


Figure 31: Example of Logic diagram (not a flowchart)

8.1.5. Combinatory logic

La logique est dite *combinatoire* si, pour un même état des entrées, nous avons toujours le même état des sorties, quel que soit l'ordre des informations d'entrées (donc pas d'ordre chronologique, pas de mémoire et pas de position dans le temps).

Boolean algebra (binary algebra) is part of combinatory logic, which we cover in the following section.

8.2. BINARY ALGEBRA

8.2.1. Basic binary functions

The elementary logic functions (Boolean algebra) may be described by their truth table or their equation:

Based on 2 possible states, 0 and 1, of 2 variables, a and b:

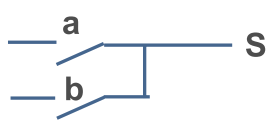
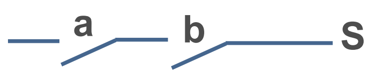
<table>
<tr><th>Logic sum</th><th>Logic product</th><th>Complementarity</th></tr>
<tr>
<td><table><tr><td>b \ a</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table>S</td>
<td><table><tr><td>b \ a</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>1</td><td>0</td><td>1</td></tr></table>S</td>
<td><table><tr><td>a</td><td>$\overline{a}$</td></tr><tr><td>1</td><td>0</td></tr><tr><td>0</td><td>1</td></tr></table></td>
</tr>
<tr>
<td>
</td>
<td>
</td>
<td></td>
</tr>
<tr>
<td>$S = a + b$
OR Function</td>
<td>$S = a \times b$
AND Function</td>
<td>$a = \overline{a}$
NOT Function</td>
</tr>
<tr>
<td>Just one variable needs to be in state 1 for the output to be in state 1</td>
<td>Both variables, or all the variables in series need to be in state 1 for the output to be in state 1</td>
<td>The input value is inverted</td>
</tr>
</table>

Table 2: Basic binary functions

8.2.2. Binary algebra properties

Here are all the properties relating to binary algebra.

Commutativity	Associativity	Distributivity
a + b = b + a a . b = b . a	a . (b . c) = (a . b) . c = a . b . c a + (b + c) = (a + b) + c = a + b + c	a + (b . c) = (a + b) . (a + c) a .(b + c) = (a . b) + (a . c)
Absorption	**Neutral element**	**Theorem: de Morgan's**
a + (a . b) = a	a + 0 = a	$\overline{a+b} = \bar{a}.\bar{b}$
a . (a + b) = a	a . 1 = a	
a . 0 = 0	a . a = a	$\overline{a.b} = \bar{a}+\bar{b}$
a + 1 = 1	a + a = a	

Table 3: Binary algebra properties

8.2.2.1. Development of De Morgan's theorem:

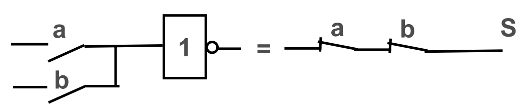
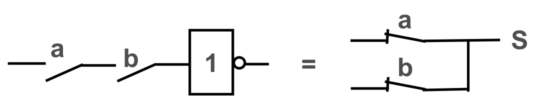
Equation	Equivalent diagrams	Truth table	Comments
$\overline{a+b} = \bar{a}.\bar{b}$		b\a	0	1 0	1	0 1	0	0 S	Both inputs need to be in state '0' for the output to have state '1'
$\overline{a.b} = \bar{a}+\bar{b}$		b\a	0	1 0	1	1 1	1	0 S	Both inputs need to be in state '1' for the output to have state '0'

Table 4: De Morgan's theorem

- The complement of a logic sum is equal to the logic product of the complemented factors of this product $\overline{a+b+c} = \bar{a}\cdot\bar{b}\cdot\bar{c}$

- The complement of a logic product is equal to the logic sum of the complemented factors of this sum $\overline{a\cdot b\cdot c} = \bar{a}+\bar{b}+\bar{c}$

8.2.2.2. Application / example with 'truth table'

An output 'S' depends on the state of 4 input variables: a, b, c, d

a	b	c	d	S
0	0	0	0	0
0	0	0	1	1
0	0	1	0	0
0	0	1	1	1
0	1	0	0	1
0	1	0	1	0
0	1	1	0	1
0	1	1	1	0
1	0	0	0	0
1	0	0	1	1
1	0	1	0	0
1	0	1	1	1
1	1	0	0	1
1	1	0	1	0
1	1	1	0	1
1	1	1	1	0

The output **S** depends on the state of 4 inputs **a**, **b**, **c**, **d**

The yellow rows in the table indicate output **S = 1**

This enables us to find the equation of **S**

Equation of output

$S = \bar{a}.\bar{b}.\bar{c}.d + \bar{a}.\bar{b}.c.d + \bar{a}.b.\bar{c}.\bar{d} + \bar{a}.b.c.\bar{d} + a.\bar{b}.\bar{c}.d + a.\bar{b}.c.d + a.b.\bar{c}.\bar{d} + a.b.c.\bar{d}$

This equation can be simplified using algebraic methods

$S = \bar{a}.\bar{b}.d + \bar{a}.b.\bar{d} + a.\bar{b}.d + a.b.\bar{d}$ (elimination of variables changing state when the others do not change)

$S = \bar{a}.\bar{b}.d + \bar{a}.b.\bar{d} + a.\bar{b}.d + a.b.\bar{d}$ (same thing with new association)

$S = \bar{b}.d + b.\bar{d}$: ***final equation***

Table 5: Application with truth table – Boolean equation

8.2.2.3. Reflected binary code

Or Gray code (a single digit changes when we pass between numbers)

Decimal code	Hexadecimal code	Pure binary code	Reflected binary code
0	0	0000	0000
1	1	0001	0001
2	2	0010	0011
3	3	0011	0010
4	4	0100	0110
5	5	0101	0111
6	6	0110	0101
7	7	0111	0100
8	8	1000	1100
9	9	1001	1101
10	A	1010	1111
11	B	1011	1110
12	C	1100	1010
13	D	1101	1011
14	E	1110	1001
15	F	1111	1000

Table 6: Gray binary code for 4 variables

This code is used for representing **Karnaugh maps**, see below

As for hexadecimals, we will take another look at them in the course on automatic controllers (PLC)

8.2.3. Composite binary functions

Basic functions may combine to create more complex structures:

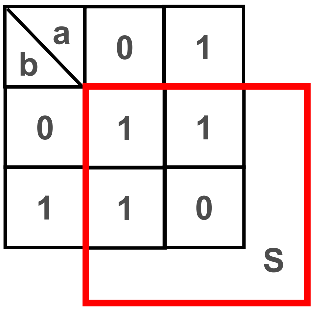
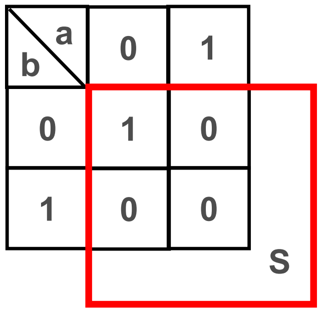
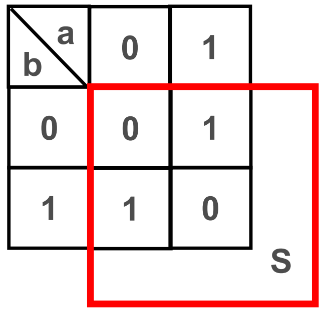
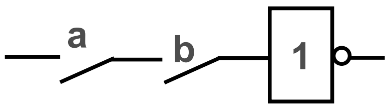
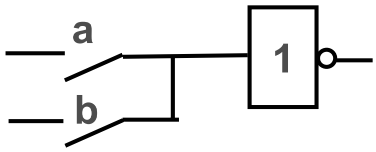
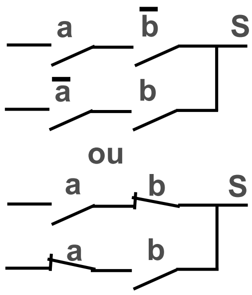
<table>
<tr><th>NAND (AND NOT)</th><th>NOR (OR NOT)</th><th>XOR (EXCLUSIVE OR)</th></tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S = \overline{a.b}$</td>
<td>$S = \overline{a+b}$</td>
<td>$S = a \oplus b = a.\bar{b} + \bar{a}.b$</td>
</tr>
<tr>
<td>Both input variables need to be in state 1 to have output state 0</td>
<td>Both input variables need to be in state ‘0’ (rest) to have output state 1</td>
<td>Both variables in the same condition give output =0</td>
</tr>
</table>

Table 7: Composite binary functions

8.2.4. Symbols for logic functions

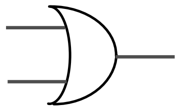
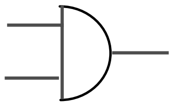
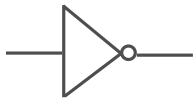
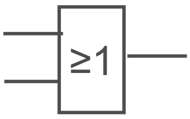
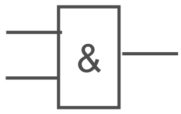
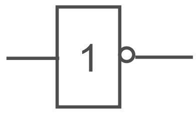
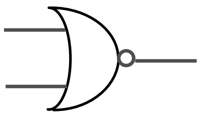
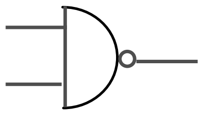
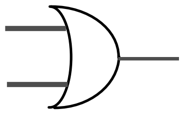
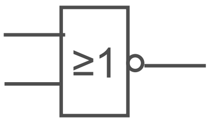
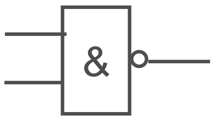
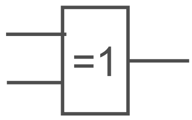
Function:	**OR**	**AND**	**NOT**
US standard			
EEC standard			
Function:	**NOR**	**NAND**	**XOR**
US standard			
EEC standard			

Table 8: Symbols for logic functions

Now we are familiar with Boolean algebra, binary code, truth tables, logic symbols (and gates), now let's take another look at how it all that blends together in terms of "logic".

8.3. KARNAUGH MAPS

There is one more thing to look at before proceeding to the applications and plotting of diagrams (and equations), which is a system used for the purposes of both assembly and simplification

8.3.1. Introduction

For the same expression, reducing the number of operators and/or number of variables expressed simplifies the writing of this expression.

There are a number of methods of simplification of Boolean expressions, among which we can make special mention of **Karnaugh map** simplification

We plot the Karnaugh map of the function to be simplified, and look for adjacent boxes which have a value of 1 and group them together, in powers of 2, into packets as big as possible.

In practice, this method has proven to be the most efficient.

8.3.2. Plotting Karnaugh maps

8.3.2.1. 3-variable map

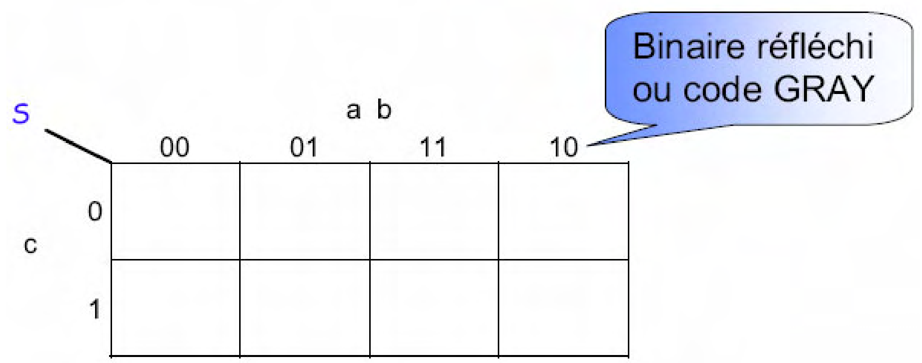


Figure 32: 3-variable Karnaugh map

Let there be 3 variables a, b, c

We place the 4 combinations of the product ab horizontally

We place the 2 combinations of c vertically

8.3.2.2. 4-variable map

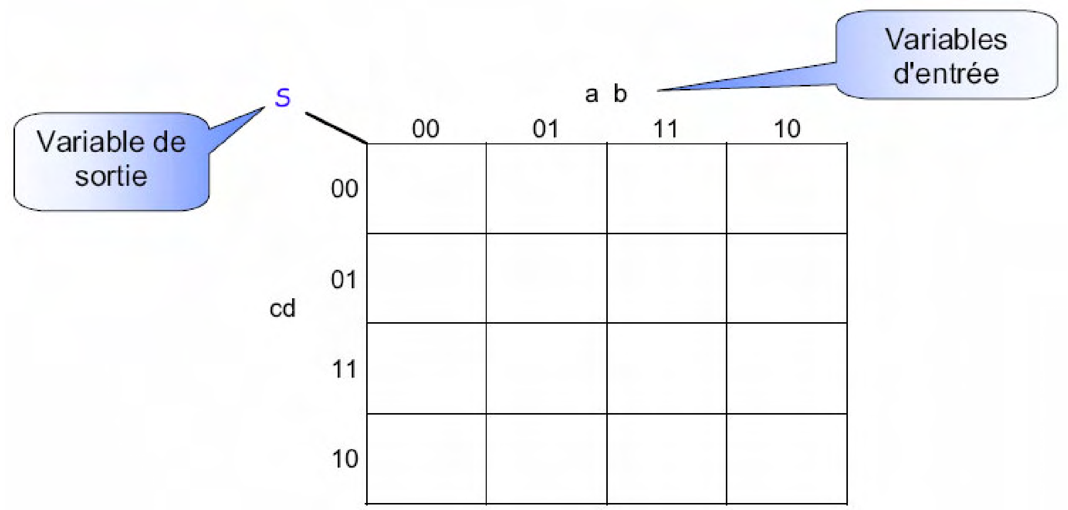


Figure 33: 3-variable Karnaugh map

The 4 combinations of ab horizontally, and the 4 combinations of cd vertically

8.3.3. Example of equation simplification

Simplification of logic equation:
with Karnaugh map.

$$S = \bar{a}\,b\,\bar{c}\,\bar{d} + abcd + a\,\bar{b}\,cd + ab\,\bar{c}\,\bar{d}$$

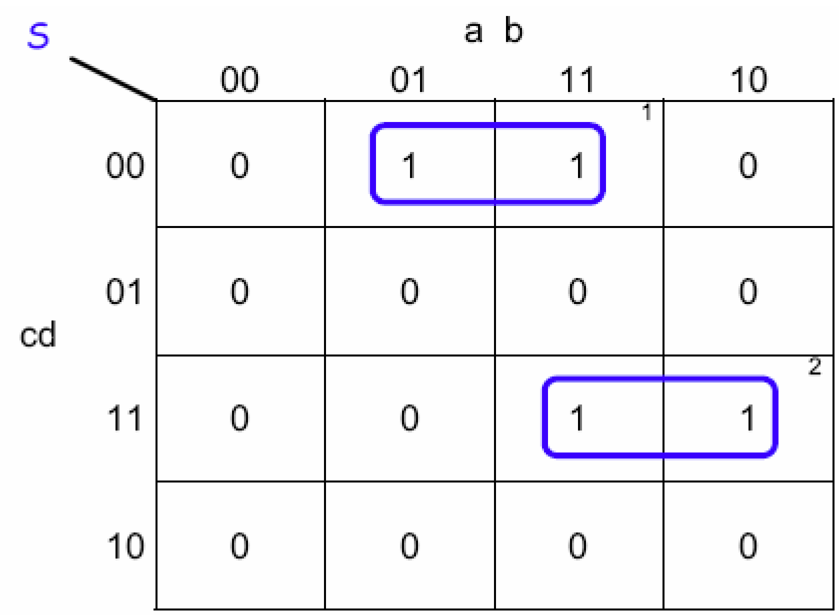


Figure 34 : Example 1 with Karnaugh map

From the map we identify the 4 combinations listed by the equation that would be the equivalent in binary code for abcd: 0100 + 1111 + 1011 + 1100

1st grouping: a changes state and is eliminated, leaving: $b\bar{c}\bar{d}$.

2nd grouping: b changes state and is eliminated, leaving: acd.

'a' and 'b' have changed state, whereas the other 3 variables were identical

The resulting equation is:

$$S = acd + b\bar{c}\bar{d}$$

(Equation reduced to polynomial or canonical in or).

Similarly for the equation

$$W = \bar{a}\bar{b}\bar{c}\bar{d} + \bar{a}\bar{b}\bar{c}d + \bar{a}\bar{b}cd + \bar{a}\bar{b}c\bar{d}$$

Equivalent to W = 0000 + 0001 + 0011 + 0010, the variables a & b remain at 0, while both others 'shift'

W: cd \ ab	00	01	11	10
00	1	0	0	0
01	1	0	0	0
11	1	0	0	0
10	1	0	0	0

$$W = \bar{a}\,\bar{b}$$

Figure 35: Example 2 with Karnaugh map

And so on

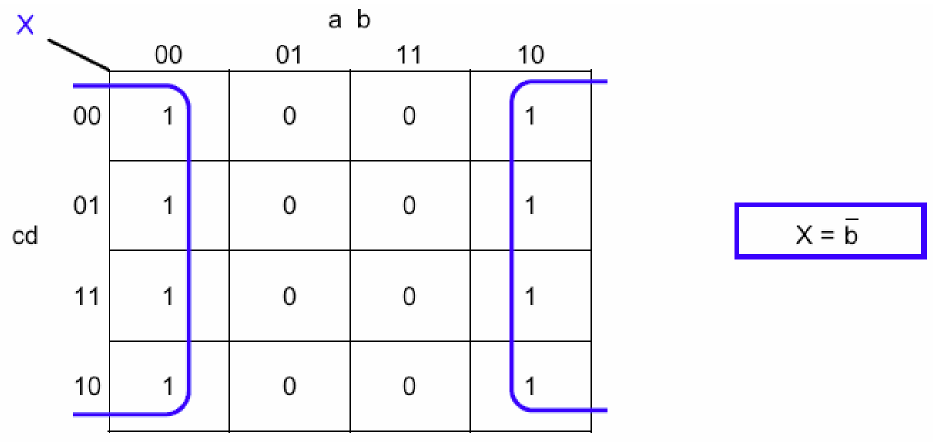


Figure 36: Example 3 with Karnaugh map

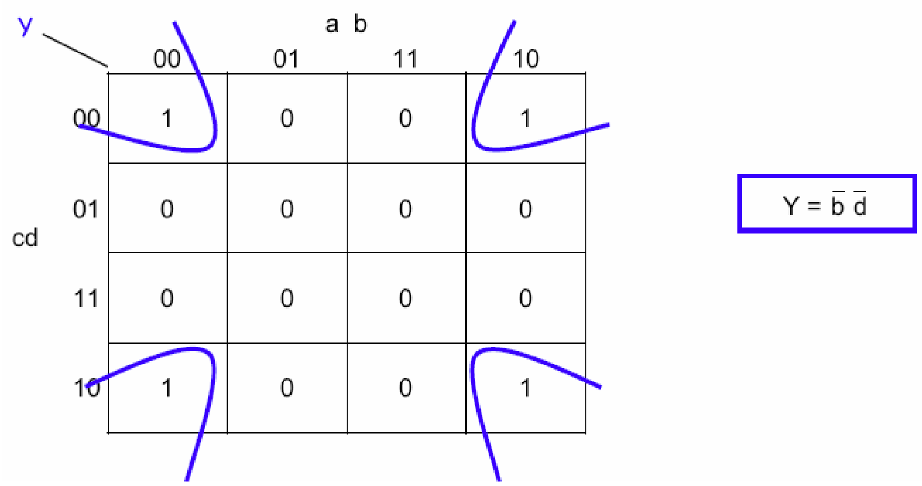


Figure 37: Example 4 with Karnaugh map

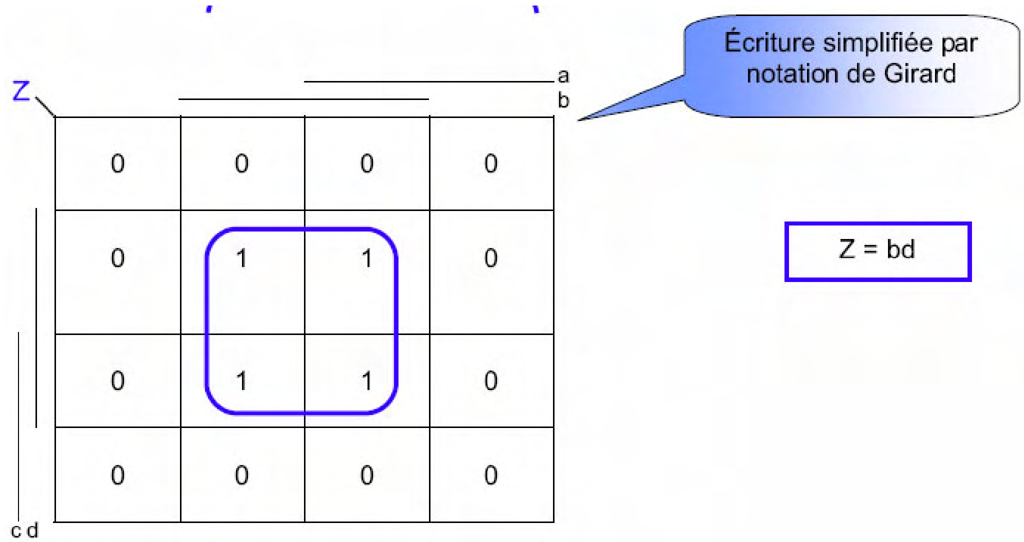


Figure 38: Example 5 with Karnaugh map

8.3.4. Exercises with Karnaugh map

9. Using the Karnaugh map, simplify the following logic equation:

$$T = \bar{a}b\bar{c}\bar{d} + ab\bar{c}\bar{d} + \bar{a}bc\bar{d} + abc\bar{d} + \bar{a}\bar{b}c\bar{d} + a\bar{b}c\bar{d}$$

T (cd \ ab)	00	01	11	10
00				
01				
11				
10				

10. Using the Karnaugh map below, find the reduced logic equation.

U (cd \ ab)	00	01	11	10
00	1	1	1	1
01	1	1	1	1
11	1	1	0	1
10	1	1	1	1

8.4. APPLICATION OF BINARY-LOGIC-KARNAUGH

8.4.1. Based on Karnaugh map

8.4.1.1. Postulation of equation with Karnaugh map

This map is used for graphically simplifying an expression

x	a b					
c d	S	0 0	0 1	1 1	1 0	It is a case of grouping **2^n** adjacent boxes in which **S = 1**
	0 0	0	1	1	0	
	0 1	1	0	0	1	We obtain two groupings Yellow: b and d do not change state (b=1 and d=0) Green: b and d v (b=0 and d=1)
	1 1	1	0	0	1	
	1 0	0	1	1	0	We do obtain the equation simplified algebraically: $S = \bar{b}.d + b.\bar{d}$

Table 9: Example of logic – truth – Karnaugh – equation

8.4.1.2. Diagrams

Based on the equation we can deduce the diagrams, since we have already looked at logic and connection diagrams

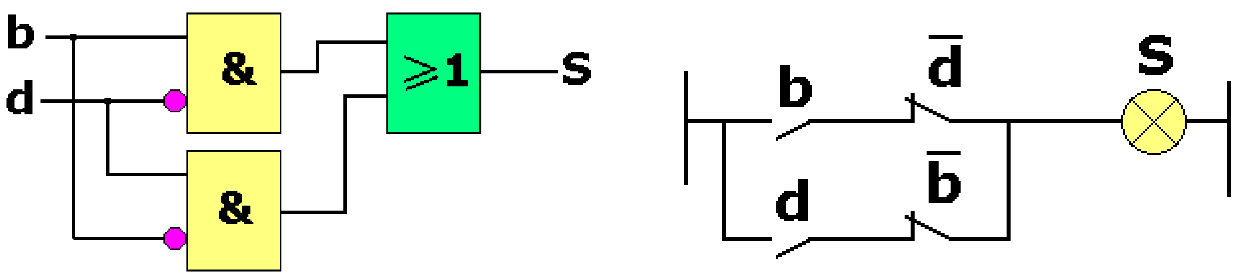


Figure 39: Logic diagram and contact diagram

8.4.2. Digital display application

Consider the application of a BCD (Binary Coded Decimal) decoder, with a 7-segment illuminated digital display

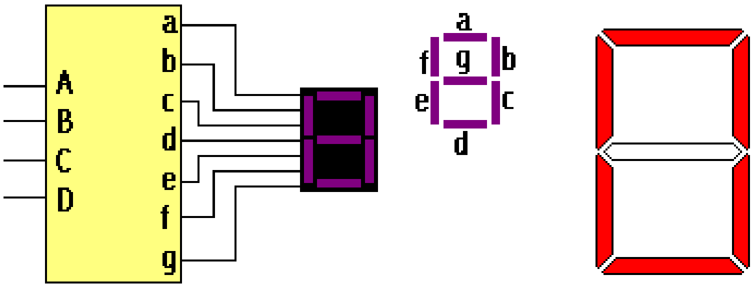


Figure 40: Digital display – 7 segments

8.4.2.1. Truth table:

According to the state, '0' or '1', of 4 input variables A, B, C, and D, corresponding to the digits 0 to 9, there will be 10 output possibilities, each of which may or may not power the 7 segments of the display.

Inputs				Outputs							Display state
D	C	B	A	a	b	c	d	e	f	g	
0	0	0	0	1	1	1	1	1	1	0	0
0	0	0	1	0	1	1	0	0	0	0	1
0	0	1	0	1	1	0	1	1	0	1	2
0	0	1	1	1	1	1	1	0	0	1	3
0	1	0	0	0	1	1	0	0	1	1	4
0	1	0	1	1	0	1	1	0	1	1	5
0	1	1	0	0	0	1	1	1	1	1	6
0	1	1	1	1	1	1	0	0	0	0	7
1	0	0	0	1	1	1	1	1	1	1	8
1	0	0	1	1	1	1	0	0	1	1	9

Table 10: Truth table for digital display

8.4.2.2. Karnaugh maps:

a		AB 00	01	11	10
CD	00	1	1	1	0
	01	1	x	x	1
	11	x	x	x	x
	10	0	0	1	1

$a = \overline{A}.\overline{C} + A.B + D + A.C$

b		AB 00	01	11	10
CD	00	1	1	1	1
	01	1	x	x	1
	11	x	x	x	x
	10	1	0	1	0

$b = \overline{A}.\overline{B} + \overline{C} + A.B$

c		AB 00	01	11	10
CD	00	1	0	1	1
	01	1	x	x	1
	11	x	x	x	x
	10	1	1	1	1

$c = \overline{B} + A + C$

d		AB 00	01	11	10
CD	00	1	1	1	0
	01	1	x	x	0
	11	x	x	x	x
	10	0	1	0	1

$d = A.\overline{B}.C + \overline{A}.\overline{C} + \overline{A}.B + B.\overline{C}$

e		AB 00	01	11	10
CD	00	1	1	0	0
	01	1	x	x	0
	11	x	x	x	x
	10	0	1	0	0

$e = \overline{A} . \overline{C} + \overline{A} . B$

f		AB 00	01	11	10
CD	00	1	0	0	0
	01	1	x	x	1
	11	x	x	x	x
	10	1	1	0	1

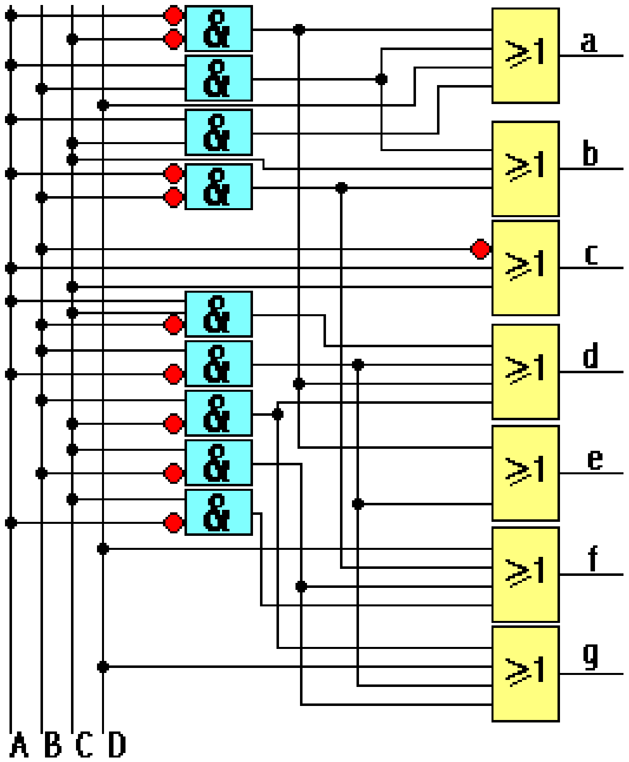
$f = C . \overline{B} + D + \overline{A} . \overline{B} + \overline{A} . C$

g		AB 00	01	11	10
CD	00	0	1	1	0
	01	1	x	x	1
	11	x	x	x	x
	10	1	1	0	1

$g = B.\overline{C} + D + \overline{A}.B + \overline{B}.C$

Table 11: Karnaugh maps for digital display

8.4.2.3. Final logic diagram



And, to switch back to reality, to get the '1' for example, we need to go back to the truth table, and change 'A' to state '1' (the other 3 remain at '0'), while at the output segments b and c will be supplied.

If you want to make a counter or count-down (or a clock), you need to add another logic to A, B, C, D, changing states '0' and '1' with time

For a multimeter with 3 or 4 "digits", it is the same system 3 or 4 times over, with in addition an increment to the next digit up in the analogue value…….

Figure 41: Logic diagram of 7-segment digital display

8.4.3. Based on a statement

8.4.3.1. Definition of specifications

We are requested to construct a small combinatory automated system comprising three inputs a b c, and an output f. The specifications document describes the operation below:
The output f must be active when:

- The three sensors associated with inputs a b c are in logic state 0 simultaneously
- The sensor associated with input c is in logic state 1, and the sensor associated with input b is at 0
- The sensor associated with input b is the only one in logic state 1

8.4.3.2. Representation by truth table

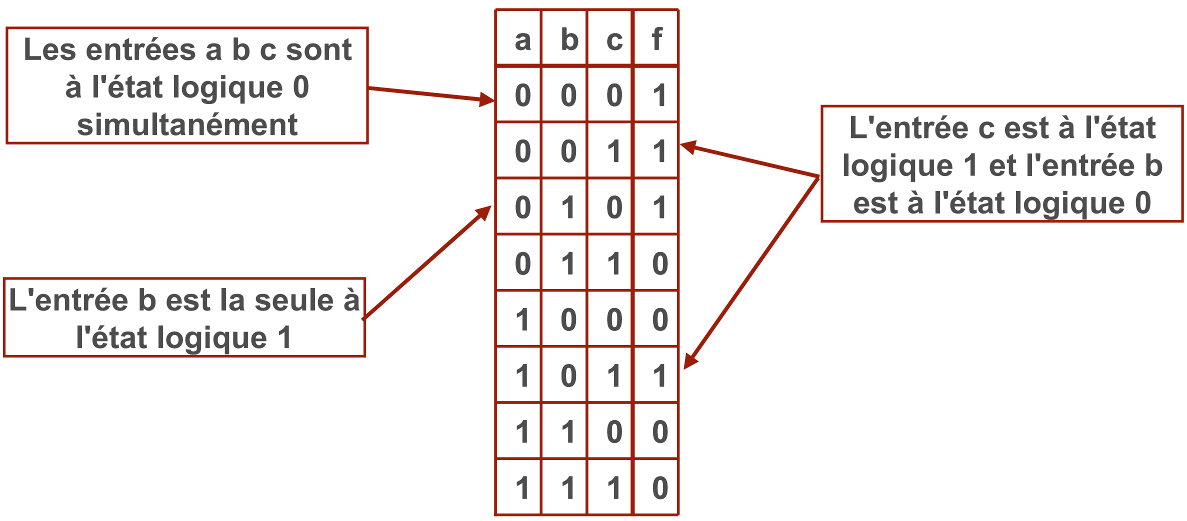
Number of input variables	Number of rows
1	2
2	4
3	8
4	16
5	32
6	64

The truth table of a combinatory system (combinatory: the output variable depends exclusively on the state of the input variables) comprises a number of columns equal to the number of input variables, plus one corresponding to the output variable.

The number of rows is equal to the total number of combinations of input variables, ***i.e.:*** $\mathbf{2^{\textit{no. of inputs}}}$

Table 12: Truth table, rows/columns relation

In a table with three inputs (a, b and c) and one output (f), we place the states depending on the specifications document: output f is at 1 if … which gives the table below.



a	b	c	f
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

Figure 42: Truth table, example of statement

From this table we try to extract the equation to establish the synthesis of the automatic system.

In the table we look for states where **f** is at **1,** and then we look for the combination of inputs enabling this state.

If there is a **1** under the variable, we take this variable, however if there is a **0,** we take the complement of this variable.

The different variables need to be positioned together, which converts to an **AND** between the different variables.

However, output **f** is at **1** for four input variable combinations. So the four equations will be connected by an **OR** between the different groupings.

a	b	c	f
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

$F = \bar{a}.\bar{b}.\bar{c}$

$F = \bar{a}.\bar{b}.c$

$F = \bar{a}.b.c$

$F = a.\bar{b}.c$

Figure 43: Equation based on truth table

Which gives us the equation below:

$$f = \bar{a}.\bar{b}.\bar{c} + \bar{a}.\bar{b}.c + \bar{a}.b.\bar{c} + a.\bar{b}.c$$

8.4.3.3. Set-up using logic gates:

This function can be set up using gates:

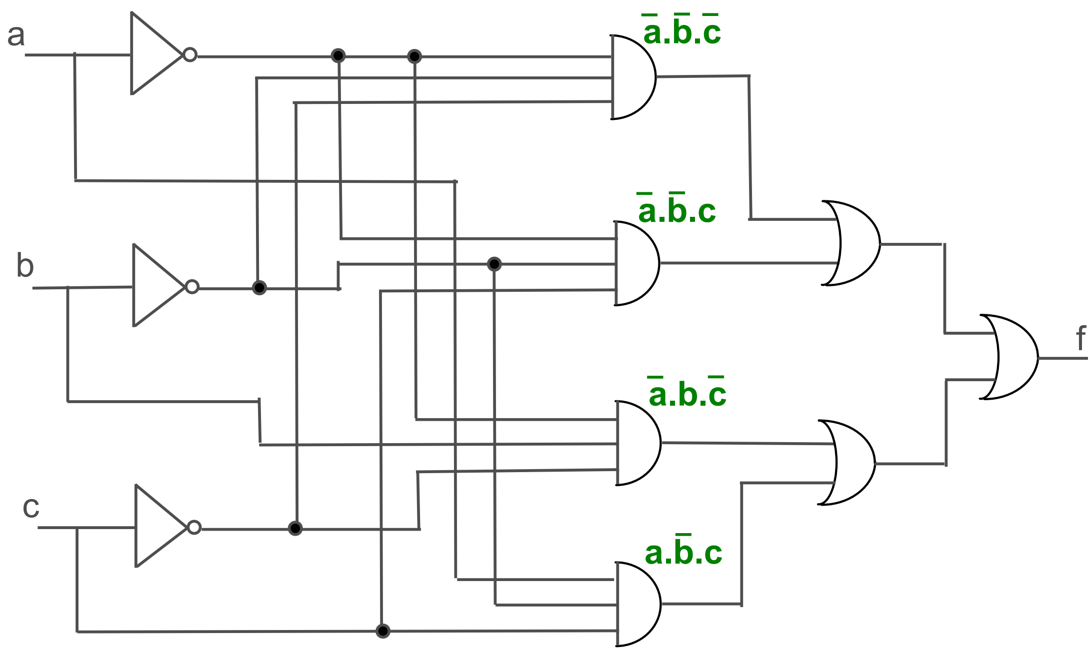
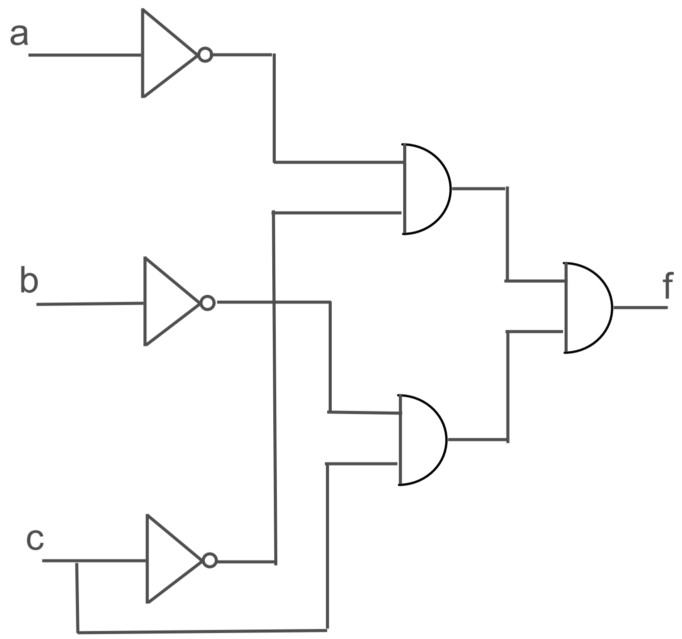


Figure 44: Diagram of set-up with logic gates

8.4.3.4. Mathematical simplification of equation

The type of set-up above requires a large number of logic gates, whereas the function f can be simplified mathematically using the properties of binary algebra:



$$f = \bar{a}.\bar{b}.\bar{c} + \bar{a}.\bar{b}.c + \bar{a}.b.\bar{c} + a.\bar{b}.c$$

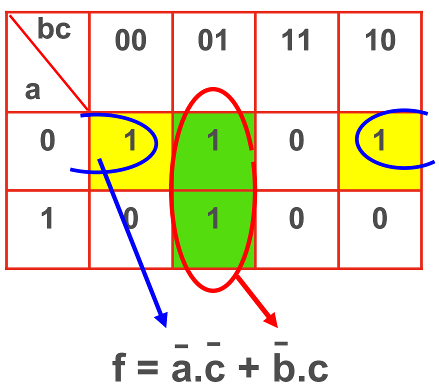
$$f = \bar{a}.\bar{c}.(\bar{b}+b) + \bar{b}.c.(\bar{a}+a)$$

$$f = \bar{a}.\bar{c} + \bar{b}.c$$

This provides us with a simpler set-up.

Figure 45: Simplified diagram of set-up with logic gates

8.4.3.5. Simplification of equation using KARNAUGH map



The KARNAUGH method can simplify logic equations for systems with up to 5 inputs.

Figure 46: Simplification with Karnaugh map

We plot a map where each box corresponds to one logic combination of inputs, and where we go from on column or row to another only modifying one input variable. We then fill in the map using the truth table, and then group together contiguous boxes in multiples of 2^n (1, 2, 4, 8…) containing the output value "1". We only retain the sum of the products of the variables corresponding to the input variables not changing state.

The equation obtained is the same as that obtained above.

As for 'more complicated diagrams', we will have the chance to look at them in the 'automatic controllers' course, and in the instrumentation course

8.5. LOGIC EXERCISES

11. Which representation do we use to represent logic functions in diagram form?

- ☐ equation form
- ☐ truth table
- ☐ Karnaugh map
- ☐ logic diagram

12. Which is the logic function described as follows: in its three-variable truth table (*a*, *b* and *c*), the output column only has one 1, when the three variables are at 0.

- ☐ AND function
- ☐ OR function
- ☐ NOR function
- ☐ NAND function

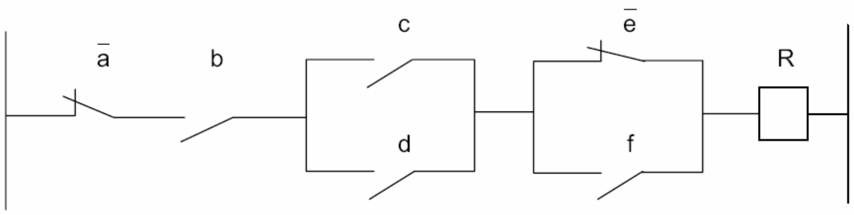
13. Which function is described here: in its three-variable truth table (*a*, *b* and *c*), the output column only has one 0, when the three variables are at 1.

- ☐ AND function
- ☐ OR function
- ☐ NOR function
- ☐ NAND function

14. Karnaugh maps are primarily used:

- ☐ for postulating logic equations
- ☐ for solving equations
- ☐ for transcribing logic equations
- ☐ for simplifying logic equations

15. Convert the contacts diagram to logic equation form.



16. Knowing that $S = a + \overline{b \cdot c}$, represent the contacts diagram and logic diagram.

17. Plot an OR function with NOR functions.

18. Plot the logic diagram of the logic equation $R = (m + r) \cdot \overline{a}$

- using OR, AND, NOT functions.

- using only NAND functions.

19. Based on the truth table below, find the equation for the output S (without reducing the equation).

a	b	c	S
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

S = ………………………………………………

20. Based on the Karnaugh map below, find the reduced logic equation.

R: cd \ ab	00	01	11	10
00	1	0	0	1
01	1	0	0	1
11	1	0	0	1
10	1	0	0	1

R = ………………………………………………

21. Simplify the logic equation below:

$$T = \bar{a}b\bar{c}\bar{d} + ab\bar{c}\bar{d} + \bar{a}bc\bar{d} + abc\bar{d} + \bar{a}\bar{b}c\bar{d} + a\bar{b}c\bar{d}$$

9. GRAFCET

In this case the aim is not to make you a specialist in GRAFCET reading and design, but to give you the tools in order to at least understand an existing GRAFCET. Below you will find all (or nearly) all the references for standards of creation.

GRAFCETS are a step or interface used (primarily) for drawing up automated system sequences, a tool for coding automatic controller programs.

In our industry, the principle of logic diagrams and "GRAFCET methods" are also used in ‘operating manuals’ to describe process sequences.

In this section, there are no exercises and/or applications provided; you will find examples and exercises in the programmable logic controllers course (PLC).

9.1. AUTOMATED PRODUCTION SYSTEM (APS) STRUCTURE

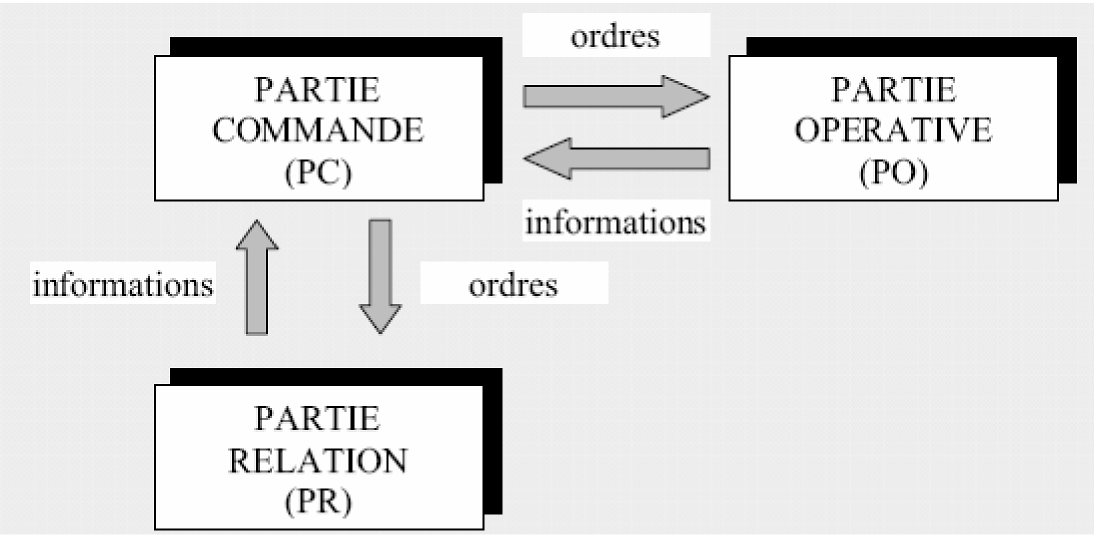


Figure 47: Structure of an automated production system

Before getting into the design of GRAFCET diagrams, let's (re)define the structure of an element; of a system, of a production installation. They consist of the human / process interface managed by instrumentation, automated systems, electro-mechanical distribution and motors/actuators

Automated production systems have three constituent parts:

- Operative part
- Relational part
- Control part

9.1.1. Operative Part (OP)

Operates on the work material and the product.

It encompasses:

- **sensors,** which cover all the functions in the acquisition chain: ram strokes, position detector, temperature sensor, analogue or digital process value, etc.)
- **pre-actuators**: elements performing the following functions:
  - adapting the low energy level available at CP (Control Part) output to the needs of the OP;
  - distributing or modulating the energy supplied to the actuators (contactor, distributor, variable speed control,…).
- **actuators**: elements for converting energy to adapt it to the requirements of the operative part; this energy is then consumed by effectors (motor, ram, electromagnet, heating resistor, etc.);

9.1.2. Relational Part (RP)

This contains the human - machine dialogue console equipped with control elements enabling the installation to be powered on/off, selection of operating modes, manual control of actuators, referencing, starting cycles, emergency shutdown… as well as various signalling functions such as indicator lights, displays, video screens, horns, buzzers, etc.

9.1.3. Control Part (CP)

Covers components (electromagnetic relay, logic operator, etc.) and constituents (PLC, microprocessor boards, micro-computers, etc.) designed for processing information transmitted by RP control elements and OP sensors.

The resulting orders are sent to pre-actuators in the OP and signalling components in the RP to tell the operator the status and situation of the system.
The "viewpoint" dimension characterises the situation of the observer describing the automated system.

9.2. CONCEPT OF VIEWPOINT

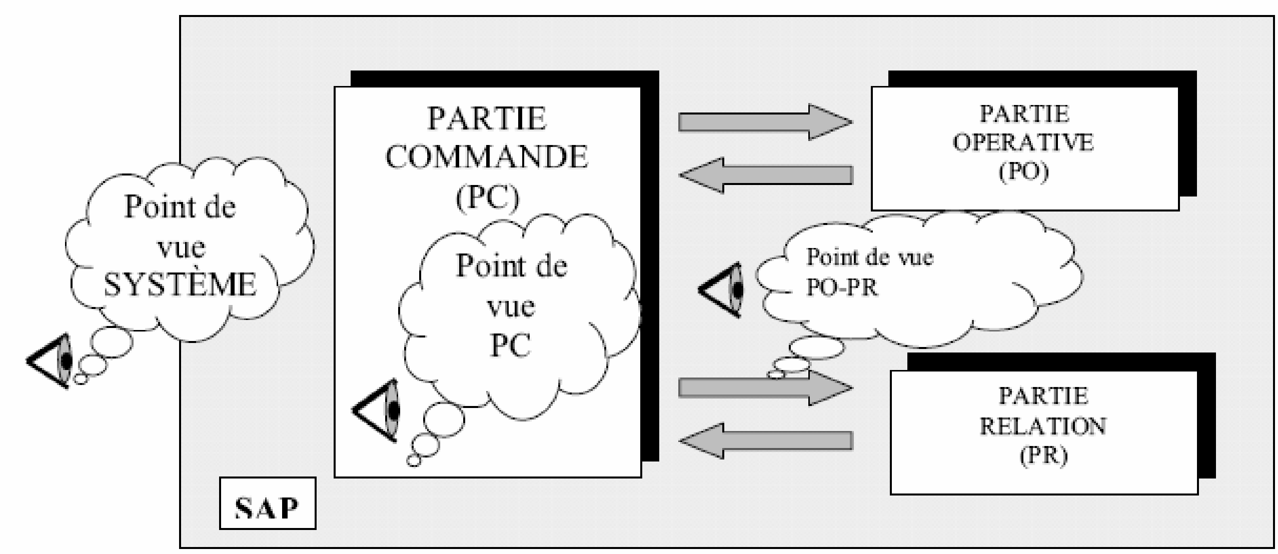


Figure 48: Concept of system viewpoint

9.2.1. System viewpoint (procedure and process)

Description made by an observer from a viewpoint outside the APS.

The system viewpoint describes the behaviour of the system in relation to the product.

The procedure is the sum of the successive functions performed on the same product in the course of its manufacture.

The process is the organisation of the procedure, the sequence of simultaneous functions performed on all products present in the automated system.

*The **GRAFCET** of the system viewpoint enables dialogue between the customer and designer regarding specification of automated systems.*

9.2.2. Operative part viewpoint

Description of system behaviour made by an observer from a viewpoint inside the APS, and outside the CP. The technological choices of the OP are made.

The operative part viewpoint describes the actions produced by the actuators from the information acquired by the sensors.

The GRAFCET of the operative part viewpoint enables dialogue between the designer of the operative part and the designer of the control part.

The notation here may be literal (e.g.: gate closed) or in symbol form, using tags from the technical file.

9.2.3. Control part viewpoint

Description of system behaviour made by an observer with a viewpoint inside the CP

This GRAFCET takes into account **the technological choices** and all **CP↔ OP** and **CP↔ Operator** exchanges. It initially describes normal operation, and may be altered with the operating modes and stoppages imposed by the specifications of the automated system.

This is the GRAFCET of the Control Part designer's viewpoint

The notation adopted in this case is notation in symbol form, using tags from the technical file.

9.3. GRAFCET MODEL

AFCET (French Association for Economic and Technical Cybernetics) and ADEPA (French National Agency for Development of Automated Production) developed a graphic representation which provided an unambiguous representation of the evolution of a sequential automated system cycle.

This functional diagram, the GRAFCET (or Sequential Function Chart), can describe expected automated system behaviour, imposing a rigorous approach, and thereby avoiding functional inconsistencies.

9.3.1. Definitions

The model is defined by an assembly comprising:

- **Basic graphic elements** comprising: steps, transitions, oriented links.
- **an interpretation** representing the behaviour of the control part with regard to its inputs and outputs, and characterised by the receptivities associated with the transitions and actions associated with the steps.
- **5 evolution rules** formally defining the dynamic behaviour of the control part.
- **Hypotheses on time-scales** for evolution.

9.3.2. Basic graphic elements

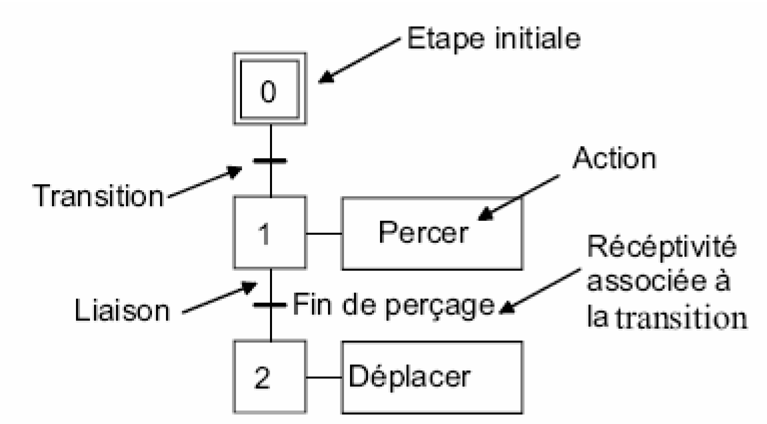


Figure 49: GRAFCET basic graphic elements

Step: a step represents a stable situation of the CP

A step is either active or inactive. Each step i can have an associated variable Xi, representing its activity.

e.g.: Step 2 active ⟶ X2 = 1 Step 2 inactive ⟶ X2 = 0

Initial step: step active at start of operation. This is represented by a double square.

Oriented links:
These link the steps to the transitions, and the transitions to the steps. The general direction of evolution is top-down. Otherwise, arrows need to be used

Transitions: a transition indicates a possible evolution of activity between two or more steps. This evolution is achieved by crossover of the transition.

Receptivity: The receptivity associated with a transition is a logic function:

- of the inputs (sensors, operator control)
- of step activities (E.g.: X1 for step 1 active.)
- auxiliary variables (E.g.: [C1=10] for a test on counter C1)

***Action**:* An action, in a rectangle, indicates how to act on the output variable, either by assignment (continuous action), or by allocation (stored action)

9.4. EVOLUTION RULES

Rule 1: Initial situation

The initial situation is the situation at the initial moment, so is described by all the steps active at that moment.

Rule 2: Transition crossover

A transition is enabled when all the immediately preceding steps linked to this transition are active. Transition crossover occurs:

- when the transition is **ENABLED**;
- **AND** the receptivity associated with this transition is **TRUE**.

Rule 3: Evolution of active steps

Crossover of a transition simultaneously leads to:

- Activation of all the immediately following steps.
- Deactivation of all the immediately prior steps.

Rule 4: Simultaneous evolutions

Several transitions with simultaneously possible crossover are simultaneously crossed.

Rule 5: Simultaneous activation and deactivation of the same step

If during an evolution, the same step is both activated and deactivated, it remains active.

9.5. SYNTAX RULES

The alternation step - transition and transition – step must always be observed, whatever the sequence completed.

9.6. RECEPTIVITIES

9.6.1. Receptivities associated with transitions

Each transition has an associated logic proposition, known as receptivity, which may be true or false.

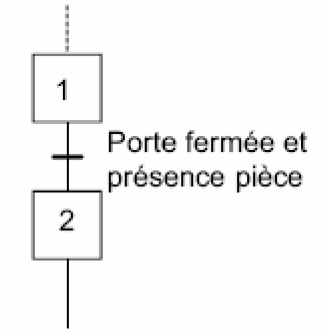


Figure 50: Textual description of receptivity

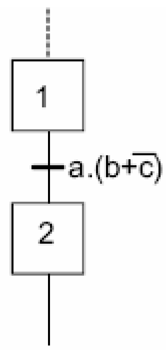
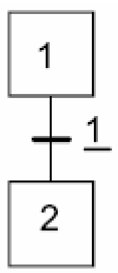


Figure 51: Boolean expression description of receptivity

9.6.2. Receptivity always true

The notation 1 (underlined) indicates that the receptivity is always true.



In this case, evolution is said to be always fleeting (see § 12), crossover of the transition is only conditional on the activity of the upstream step

Figure 52: Receptivity always true

9.6.3. Upward front and downward front of a logic variable

Upward front

The notation ↑ indicates that the receptivity is only true when the variable changes from value 0 to value 1.

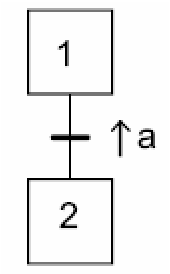


Figure 53: Receptivity is only true when a goes from state 0 to state 1

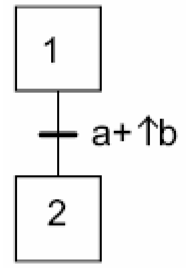
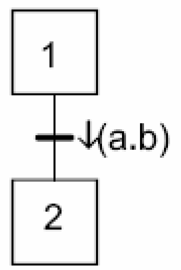


Figure 54: Receptivity is only true when a is true or b goes from state 0 to state 1

Downward front

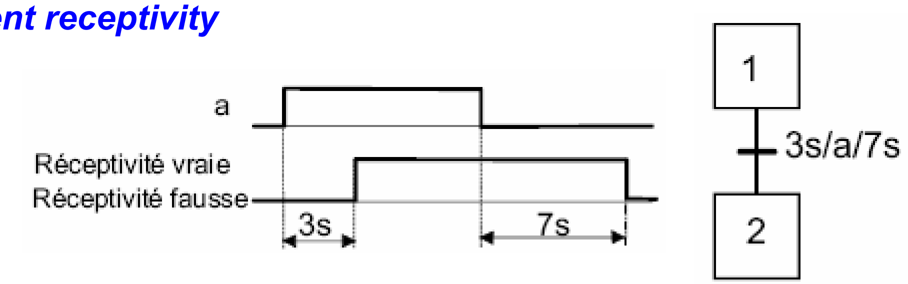


The notation ↓ indicates that the receptivity is only true when the variable changes from value 1 to value 0.

Figure 55: Receptivity is only true when the logic product "a.b" changes from state 1 to state 0

9.6.4. Time-dependent receptivity

Figure 56: Time-dependent receptivity (a)



The notation is in the form "**t1/variable/t2**". In the example above, receptivity is only true 3 secs after "a" changes from state 0 to state 1, and only becomes false again 7 secs after "a" changes from state 1 to state 0.

Standard simplification

The most common use is the step variable time-lag, with time t2 equal to zero:

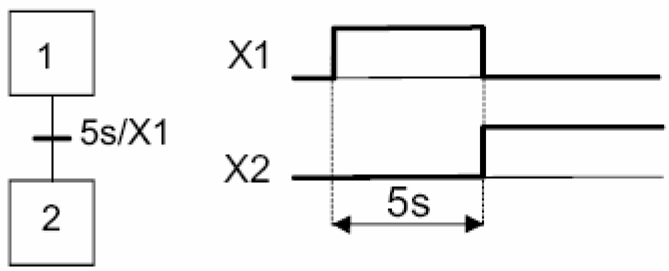


Figure 57: Time-dependent receptivity (b)

In this case the activity time of step 1 is 5 secs.

Note: It is possible to use this notation when the time-lagged step is not the step upstream of the transition.

9.6.5. Boolean value of a predicate

A predicate is an expression containing one or more variables, which can potentially become a true or false proposition.

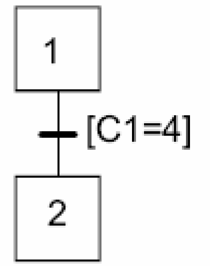


Figure 58: Example 1 Boolean value of a predicate

The receptivity is true when the current value of the counter is equal to 4.

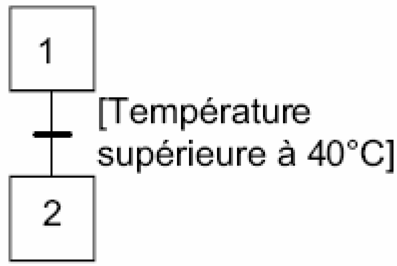


Figure 59: Example 2 Boolean value of a predicate

A literal expression can be used.

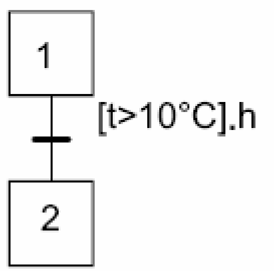


Figure 60: Example 3 Boolean value of a predicate

The receptivity is true when the temperature is greater than 10°C and high level h is reached.

9.7. ASSOCIATED ACTIONS

One or more elementary actions or complex actions may be associated with a step.

The actions represent what has to be done whenever the step with which they are associated is active. There are 2 types of actions:

- Continuous actions.
- Stored actions.

9.7.1. Continuous action

The action continues to be performed as long as the step with which it is associated is active, and the assignment condition (logic expression of input variables and/or internal variables) is verified. In the absence of conditions the action is performed as long as the step with which it is associated is active.

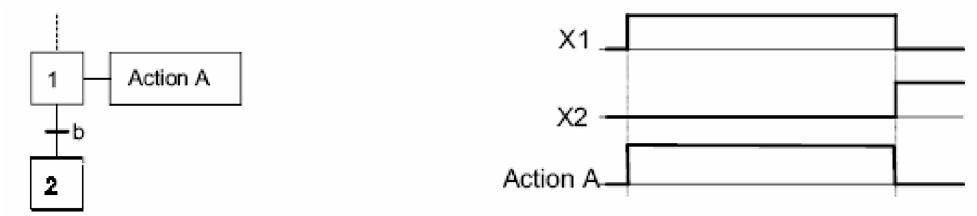


Figure 61: Continuous action (a)

A continuous action is conditional on a logic proposition, which may be true or false, known as an assignment condition.
The assignment condition must never have an input variable and/or internal variable fronts.

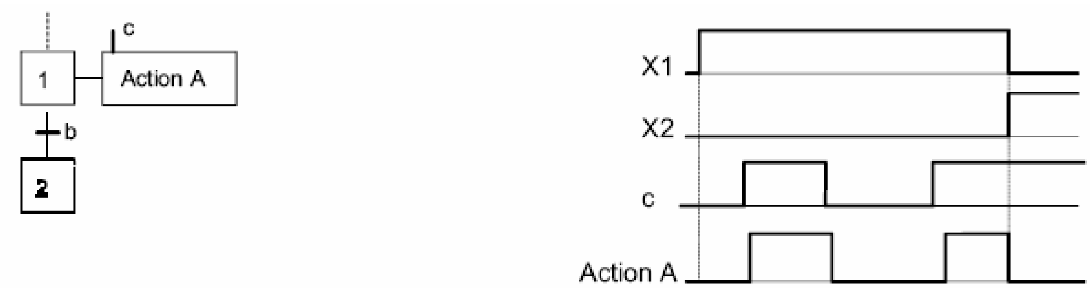


Figure 62: Continuous action (b)

The assignment condition is only true 5 seconds after "**c**" changes from state 0 to state 1 (upward front of c) ; it will only become false again 3 seconds after "**c**" changes from state 1 to state 0 (downward front of c).

Figure 63: Continuous action (c)

A delayed action is a continuous action with an assignment condition only true after a specified time t1 from activation of the associated step. In the example below, action A will be performed 5 s after activation of step 1.

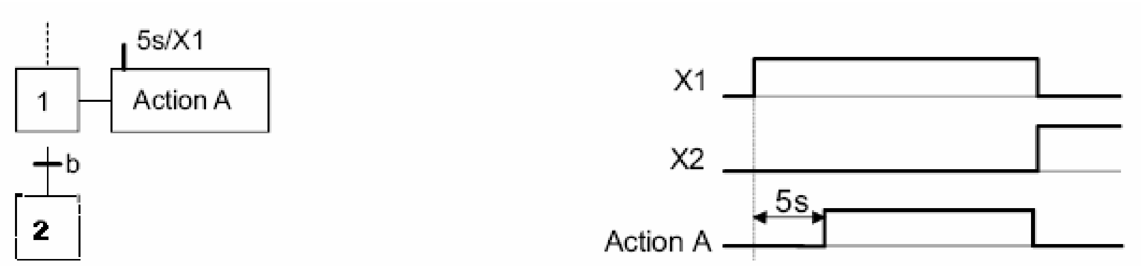


Figure 64: Continuous action (d)

A time limited action is a continuous action whose assignment condition is only true for a specified time t1 from activation of the step with which it is associated.

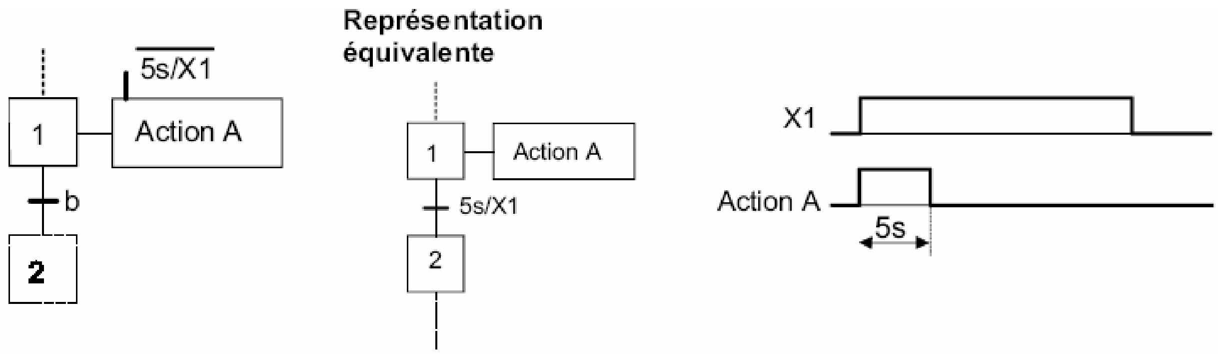
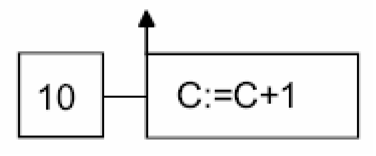


Figure 65: Continuous action (e)

9.7.2. Held or stored action

For an action to remain held when the step commanding it has just been deactivated, a stored action must be used.
In stored mode, association of an action with *internal events* can indicate that an output variable adopts and retains the imposed value if one of the events occurs.

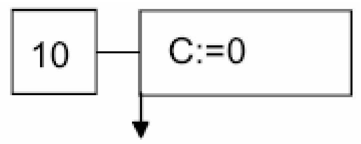
9.7.3. Action upon activation and upon deactivation



An action upon activation is an action stored upon activation of the step linked to this action.

Figure 66: Action upon activation

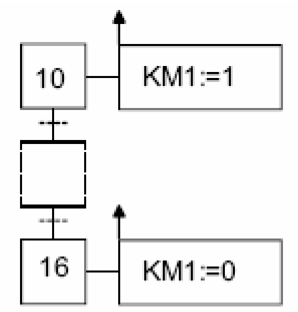
Counter C incremented upon activation of step 10



An action upon deactivation is an action stored upon deactivation of the step linked to this action.

Figure 67: Action upon deactivation

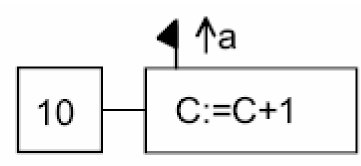
Counter C zeroed upon deactivation of step 10.



KM1=1 upon activation of step 10, remaining at 1 until activation of step 16.

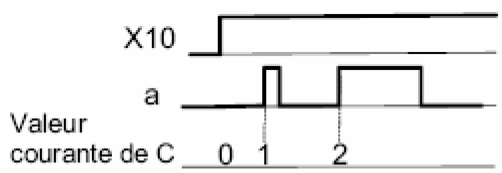
Figure 68: Action upon activation / deactivation

An action upon an **event** is a stored action conditioned by the occurrence of an event, when the step to which the action is linked is active. **It is vital for the logic expression associated with the event to have one or more input variable fronts**.



Counter C incremented upon upward front of "**a**", with step 10 active.

Figure 69: Action upon event



9.8. COMMENTS

A comment on graphic elements in a GRAFCET can be inserted in speech marks.

Figure 70: Comment

9.9. BASIC STRUCTURES

9.9.1. Linear sequence

A linear sequence comprises a string of steps which may be activated one after another

9.9.2. Sequence selection

A sequence selection is a choice of evolution between several sequences from one or more steps. It is graphically represented by the same number of transitions simultaneously enabled as there may be possible evolutions. Exclusion between sequences is not structural. To obtain it, you need to ensure either that the receptivities are mechanically or temporally incompatible, or logically exclusive.

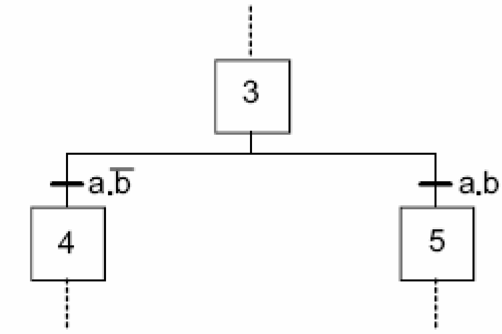
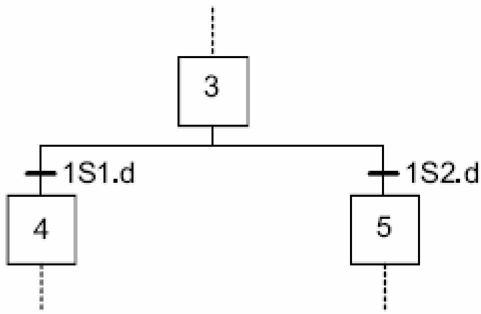


Figure 71: Logic exclusivity

Receptivities / a.b and a.b are locally exclusive.

Figure 72: Technological exclusivity

Receptivities 1S1.d and 1S2.d are technologically exclusive through travel limit sensors 1S1 and 1S2 of ram 1A. *(Assuming that there is a receiver ram)*



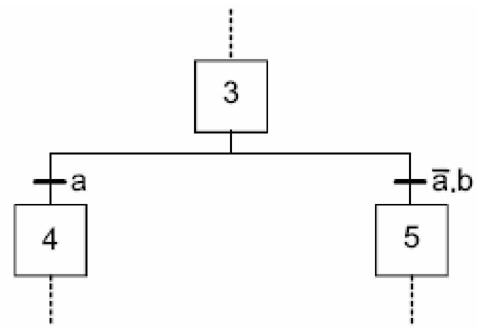


Figure 73: Exclusivity with priority

Receptivities a and /a.b are exclusive, with priority to evolution 3⟶4 over evolution 3⟶5 if a=1 and b=1.

9.9.3. Step jump and sequence restart

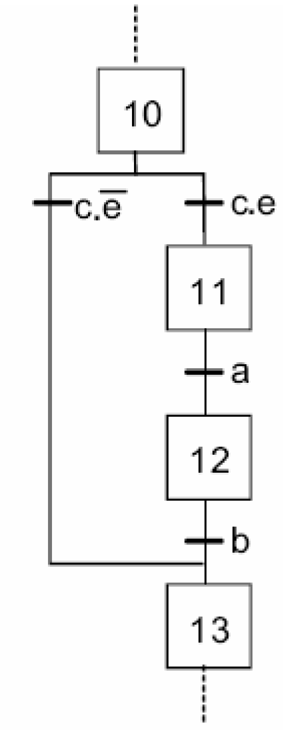
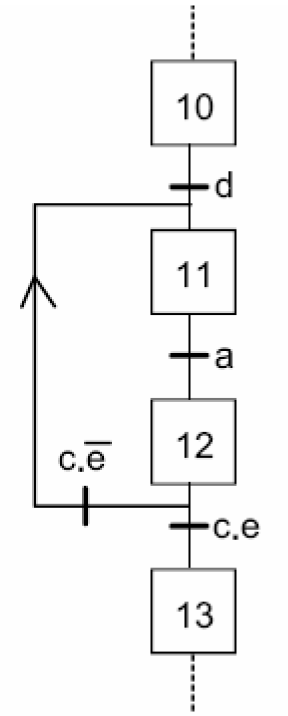


Figure 74: Step jumps

Step jumps skip one or more steps if the actions associated with these steps become useless.

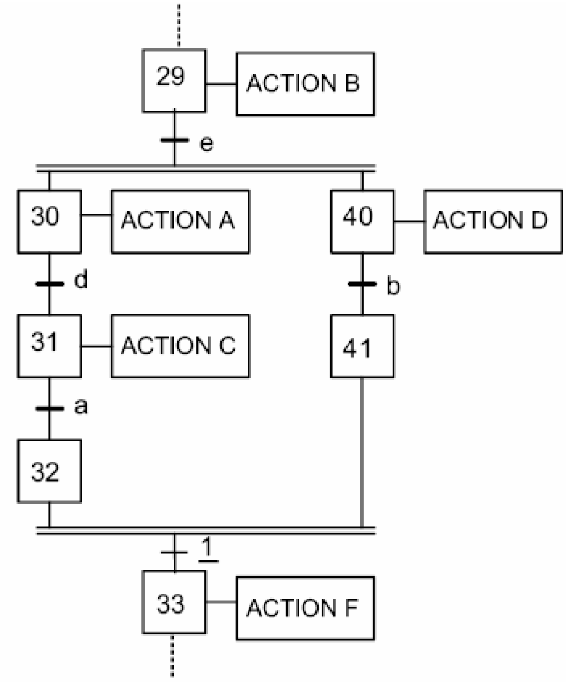
Figure 75: Sequence restart

The sequence restart can start the sequence several times over, until a condition is obtained.



9.9.4. Simultaneous sequences (parallel sequences)

If crossover of a transition activates several steps at the same time, these steps will trigger the sequences, evolution of which will be both simultaneous and independent.



If step 29 is active, receptivity "**e",** when true, simultaneously activates steps 30 and 40.

Both sequences evolve independently of each other.

Steps 32 and 41 are standby steps; once active, the transition 32,41⟶33 is crossed (1: receptivity always true), which simultaneously activates step 33 and deactivates steps 32 and 41.

Figure 76: Simultaneous sequences

Note:

- that activation of step 32 prevents action C from continuing when a is true and b is not yet true.
- that activation of step 41 prevents action D from continuing when b is true and a is not yet true.

9.10. PARTICULAR STRUCTURES

9.10.1. Source step and transition

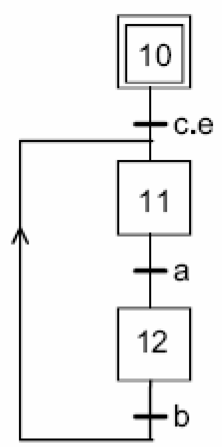


Figure 77: Source step

A source step is a step without any upstream transition. In the example opposite, the initial source step 10 is only active upon initialisation (until receptivity **c.e** is true)

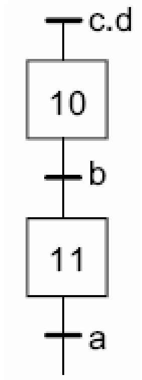


Figure 78: Source transition

A source transition is a transition without any upstream step.

By convention, the source transition is always enabled and crossed once its receptivity is true. In the example above, step 10 is activated once receptivity "**c.d**" is true.

9.10.2. Pit step and transition

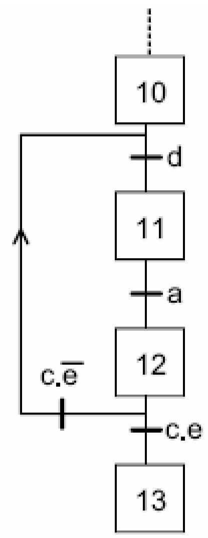


Figure 79: Pit step

A pit step is a step without any downstream transition; it can be deactivated by a forcing order from an upper level GRAFCET (see § 13)

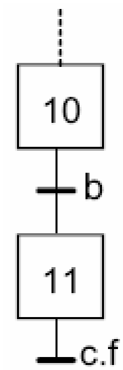


Figure 80: Pit transition

A pit transition is a transition without any downstream step.

In the example opposite, when the pit transition is validated and "**c.d"** is true, the only result of crossover of this transition is deactivating step 11.

9.11. NOTES ON ORIENTED LINKS

9.11.1. Bottom-up link

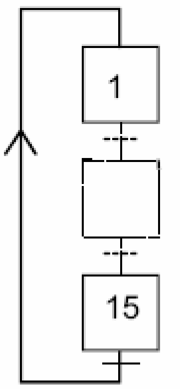


Figure 81: Recommended solution link

By convention the direction of evolution is always top-down. Arrows must be used if this convention is not observed or if their presence can aid understanding.

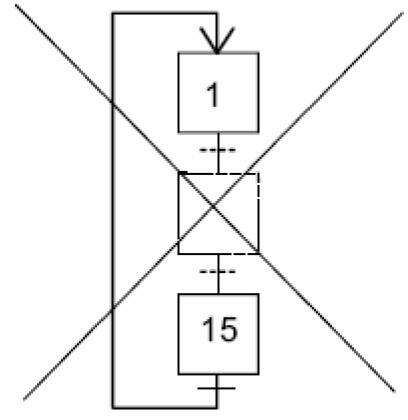


Figure 82: Solution to be avoided link

9.11.2. Link tag

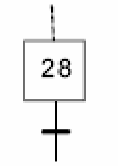


Figure 83: Link tag

If an oriented link has to be interrupted (in complex diagrams or with representation over several pages) the destination step tag and tag of the page where it appears must be indicated. Above, evolution to step 29 on page 2.

9.11.3. Case of sequence selection

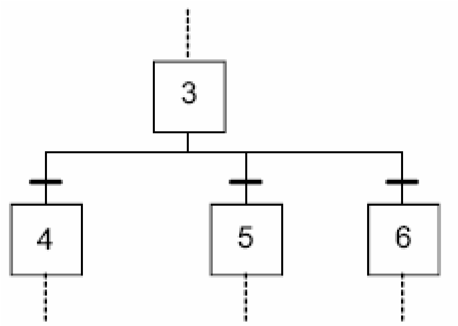


Figure 84: Sequence selection – recommended solution

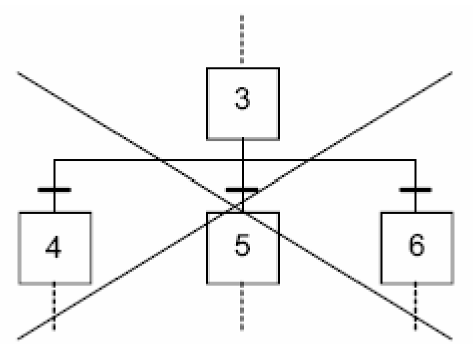


Figure 85: Sequence selection – solution to be avoided

9.12. FLEETING EVOLUTION

In certain cases, application of evolution rules may result in crossing several transitions in succession if the receptivities associated with the subsequent transitions are already true upon crossover of the first transition(s) in question.

The corresponding evolution is said to be fleeting.

The corresponding intermediate steps, known as *unstable* steps, are activated, but we consider them to have been "virtually" activated and deactivated along the intuitive evolution path, and similarly that the corresponding transitions have been "virtually" crossed.

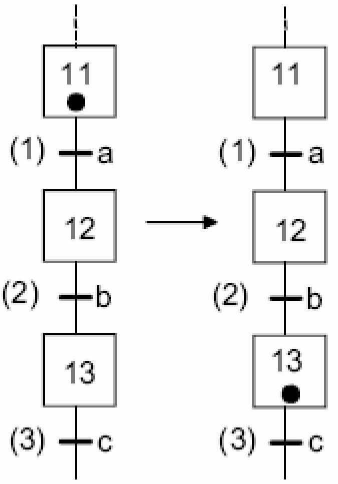


Figure 86: Example of fleeting evolution

Intuitive interpretation of evolution:
The change of value of "**a**" causes crossover of transition (1), and virtually activates step 12, and then transition (2) is virtually crossed, since b=1, resulting in the subsequent situation: step 13 active.

True interpretation of evolution:
The change of value of "**a**" directly results in the subsequent situation: step 13 active.

9.12.1. Consequence of a fleeting evolution on assignments

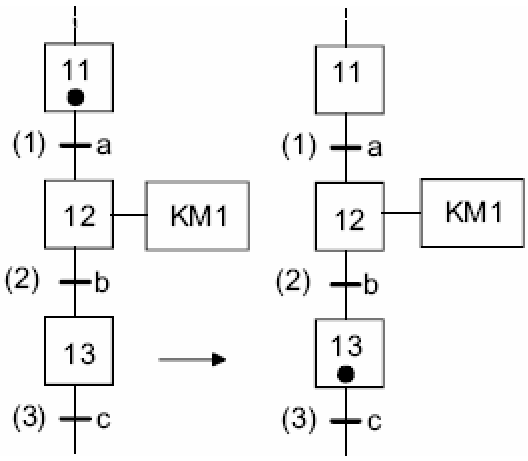


Figure 87: Example of continuous action associated with an unstable step

Prior situation: step 11 active, a=0, b=1 and c=0

The change of value of "**a**" directly results in the subsequent situation: step 13 active.

The prior situation (step 11 active) and subsequent situation (step 13 active) assign the value 0 to the output variable KM1.

As the unstable step 12 is not really activated, assignment of the value 1 to KM1 is not effective during this fleeting evolution.

9.12.2. Consequence of fleeting evolution on allocations

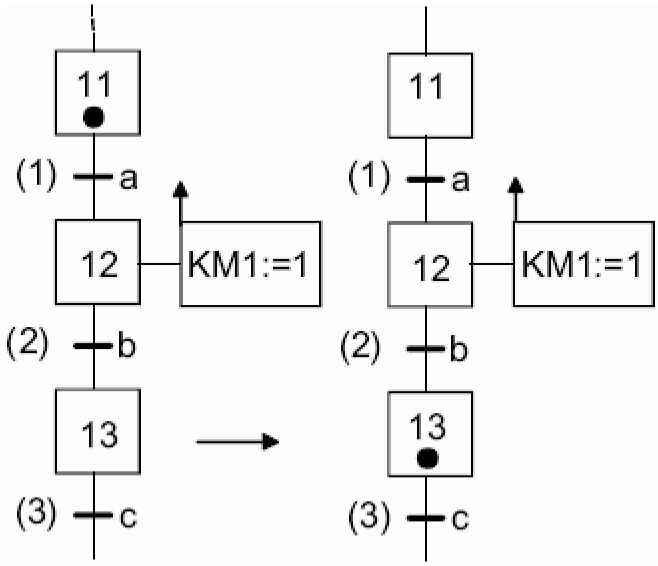


Figure 88: Example of stored action associated with activation of an unstable step

Prior situation: step 11 active, a=0, b=1 and c=0

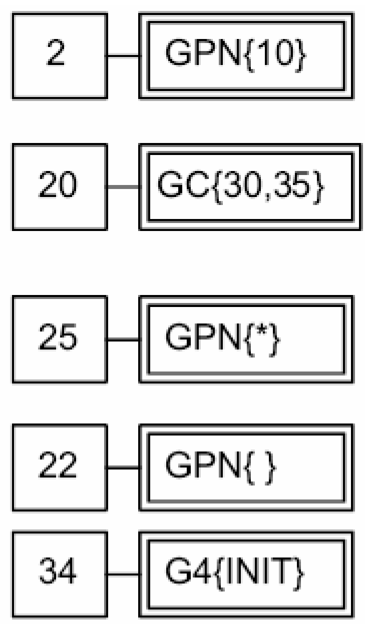
The change of value of "**a**" directly results in the subsequent situation: step 13 active.

The allocation of the value 1 to the output variable KM1 is effective, since it is the consequence of the virtual activation of step 12.

9.13. FORCED STRUCTURING OF A PARTIAL GRAFCET

The situation forcing order issued by a hierarchically higher GRAFCET can modify the current situation of a hierarchically lower GRAFCET, without transition crossover occurring.

A forcing order is an internal order with priority over all evolution conditions, with the effect of **activating the step(s)** corresponding to the **forced situation** and **deactivating the other steps** in the forced GRAFCET.



The forcing order is represented in a double rectangle associated with the step to distinguish it from an action.

If step 2 is active, the GRAFCET named GPN is forced to the situation characterised by the activity of step 10 (step 10 is activated and the other steps are deactivated).

If step 20 is active, the GRAFCET named GC is forced to the situation characterised by the activity of steps 30 and 35 (steps 30 and 35 are activated and the other steps are deactivated).

Figure 89: Forcing of a GRAFCET

If step 25 is active, the GRAFCET named GPN is forced to the situation it is in at the time of forcing.

This order is also known as "**freezing**".

If step 22 is active, the GRAFCET named GPN is forced to a nil situation. In this case none of these steps is active.

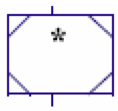
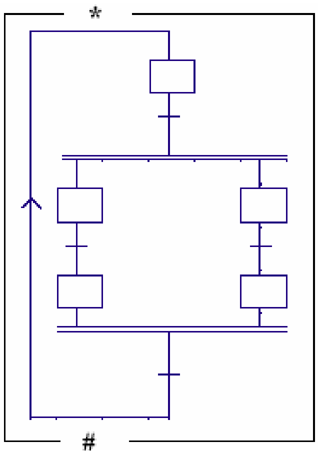
If step 34 is active, the GRAFCET named G4 is forced to the situation in which only the initial steps are active.

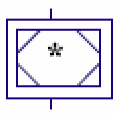
9.14. ENCAPSULATION STRUCTURE

9.14.1. Definition

There is said to be encapsulation of a set of steps, known as the encapsulated steps, by the so-called encapsulating step, on condition that when this encapsulating step is active, at least one of the encapsulated steps is active. The specifier can use encapsulation to structure a GRAFCET hierarchically.

9.14.2. Symbols and description

Symbol	Description
	**Encapsulating step:** This notation indicates that this step contains other steps, known as encapsulated steps, in one or more encapsulations of this same encapsulating step. The encapsulating step has all the properties of the step, so the asterisk should be replaced by the step tag. An encapsulating step may generate one or more encapsulations, each with at least one active step when the encapsulating step is active, and with no active steps when the encapsulating step is inactive.
	**Graphic representation of an encapsulation:** An encapsulation **#** of an encapsulating step * can be represented by the partial GRAFCET of the encapsulated steps, i.e. a box in the top-left of which appears the name ***** of the encapsulating step, and in the bottom-left the tag **#** of the encapsulation represented. In an encapsulation, all the encapsulated steps together should make up a partial GRAFCET, the name of which can be used as a tag for the corresponding encapsulation.

Symbol	Description
X*/G#	**Overall designation of an encapsulation:** An encapsulation **#** of an encapsulating step * can be given an overall description using a literal expression in which the encapsulating step * is designated by the step variable **X***, the encapsulation by the symbol **/** and the encapsulated steps by the name of the partial GRAFCET **G#** to which they belong. <u>Note:</u> this representation assumes that the partial GRAFCET designated has already been defined.
X*/X#	**Elementary designation of an encapsulation:** We can indicate using a literal expression that a step **#** is encapsulated in an encapsulating step * using the step variables and without naming the encapsulation. <u>Note:</u> this notation is suitable for designating a hierarchical string of steps encapsulated within each other, and also enables relative identification relative of steps on each encapsulation level. Example: X4/X25/X12 designates the encapsulation of step 12 in step 25, itself encapsulated in step 4.
	**Initial encapsulating step:** This representation indicates that this step is involved in the initial situation. In this case, at least one of the steps encapsulated in each of its encapsulations must also be an initial step.

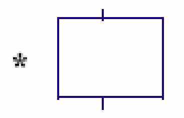
Symbol	Description
	**Activation link**: Represented by an asterisk to the left of the encapsulated step symbols, the activation link indicates which steps are active in activation of the encapsulating step. The activation link must not be confused with indication of initial steps, which may be encapsulated. However, it is possible for an encapsulated initial step to also have an activation link. Deactivation of an encapsulating step deactivates all its encapsulated steps. This deactivation is often due to crossover of a transition downstream of the encapsulating step, but can also result from any other means of deactivation (higher level forcing or encapsulation).

Table 13: Symbols / description of encapsulation

9.14.3. Example of activation link

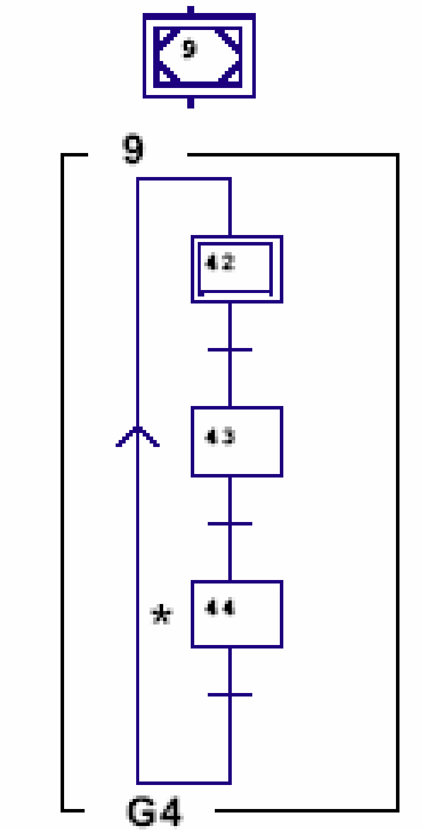


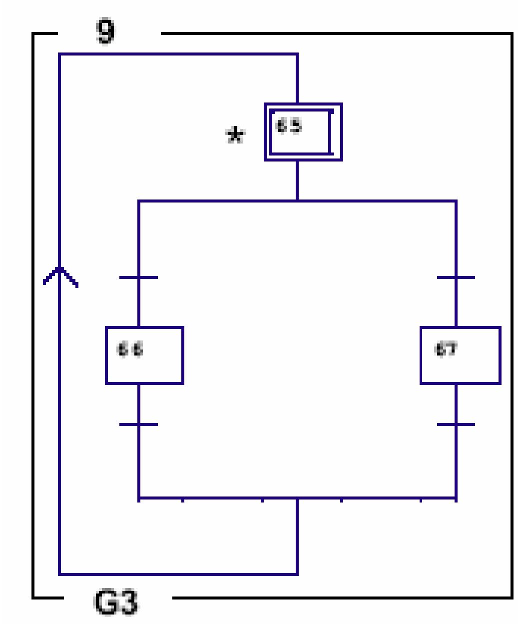
Figure 90: Example (a) of activation link

The encapsulating step 9 is necessarily an initial step, as it encapsulates initial step 42.

Encapsulation G4 of encapsulating step 9 contains steps 42, 43 and 44.

The initial step 42 is involved in the initial situation, so it is active at the initial moment. Conversely, whenever step 9 is activated, upon GRAFCET evolution, step 44 is activated.

Figure 91 : Example (b) of activation link



Encapsulation G3 of encapsulating step 9 contains steps 65, 66 and 67.

The initial step 65 is involved in the initial situation, so it is active at the initial moment. It is also activated whenever step 9 is activated upon GRAFCET evolution.

9.14.4. Example of encapsulation

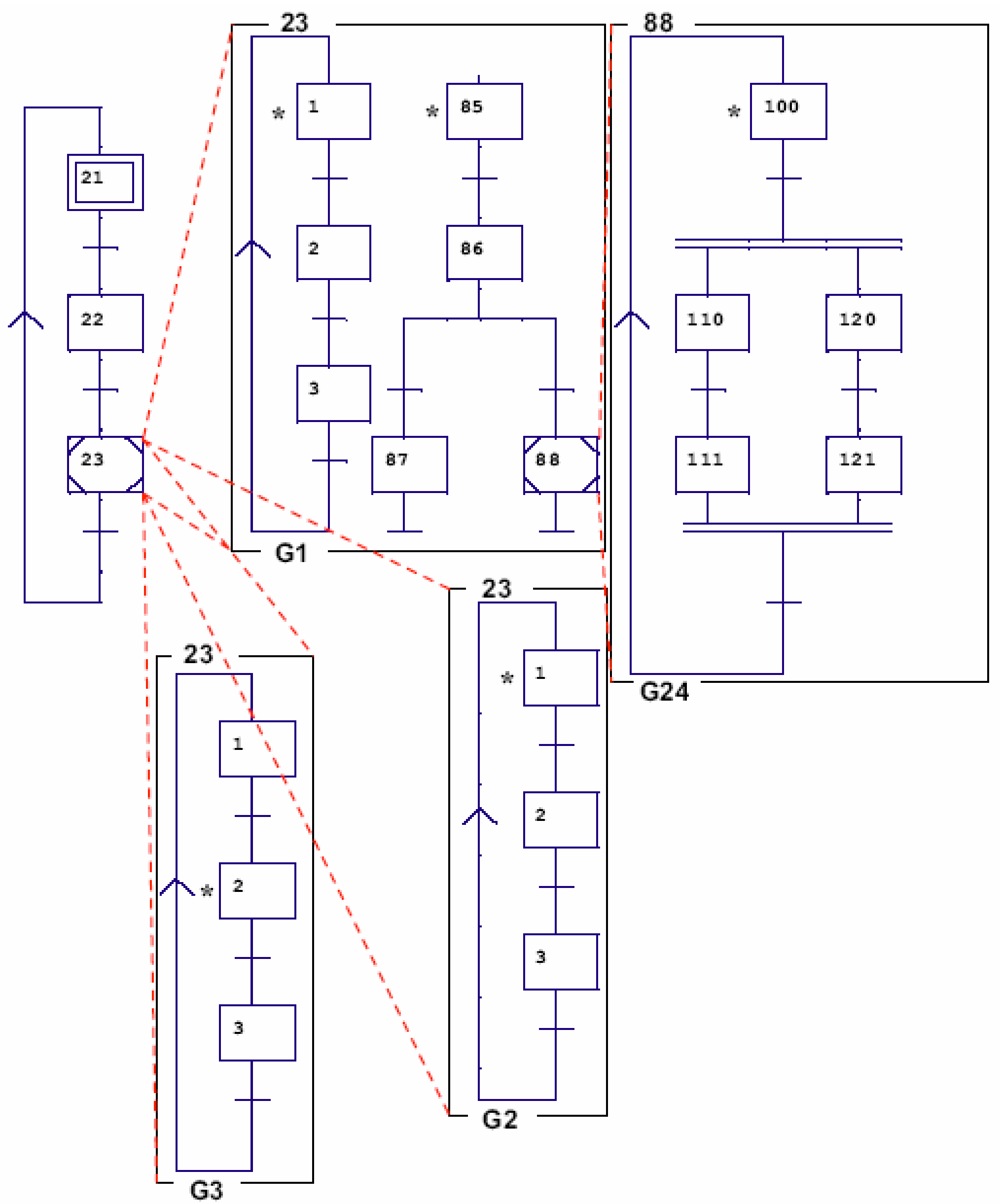


Figure 92: Example of encapsulation

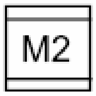
The encapsulating step 23 has 3 encapsulations represented by partial GRAFCETS 1, 2 and 3. Partial GRAFCET 24 is encapsulated by step 88 of partial GRAFCET 1. When encapsulating step 23 is activated, steps 1 and 85 of G1 are also activated (same as for the other encapsulations of 23: G2 and G3).

When the encapsulating step 88 is activated, step 100 of G24 is activated.

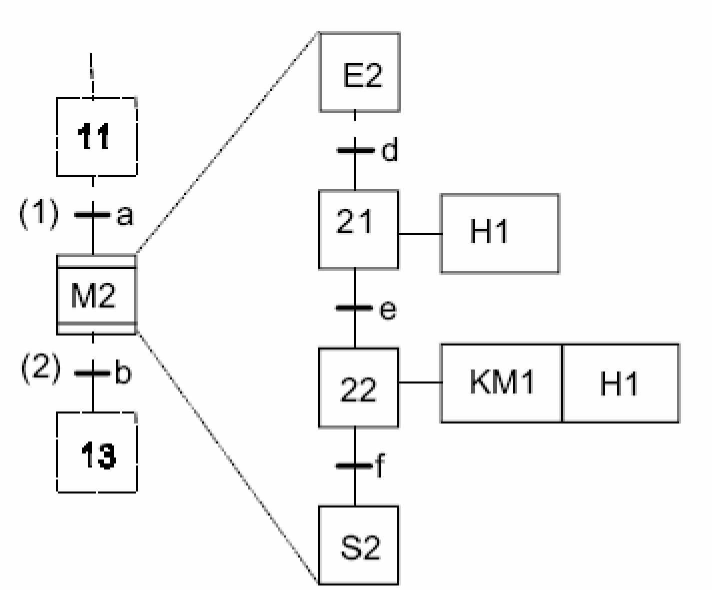
Deactivation of step 88 deactivates all the steps of G24.
Deactivation of step 23 deactivates all the steps of G1, G2, G3 and all those of G24 (if step 88 was active).

9.15. MACRO-STEP STRUCTURE

With the concept of macro-representation, we have a means of putting off or carrying over to another page the detailed description of certain sequences.



The macro-step is the unique representation of a set of steps and transitions known as the macro-step expansion.



The macro-step expansion begins with a single input step, and ends with a single output step; these steps represent the only possible links with the GRAFCET to which it belongs.

Figure 93: Example of a macro-step M2 represented with its expansion:

Crossover of transition (1) activates step E2.

Transition (2) will only be enabled when step S2 is active.

Crossover of transition (2) deactivates step S2.

9.16. GRAFCET STRUCTURING OF TASKS AND/OR SUB-PROGRAMS

Standard EN 60848 does not refer to these concepts, and so does not define graphic symbols for task management GRAFCETs. We can continue to use GRAFCET structuring of sub-program(s), indicating the name of the sub-program called in speech marks (rather than in an action rectangle).

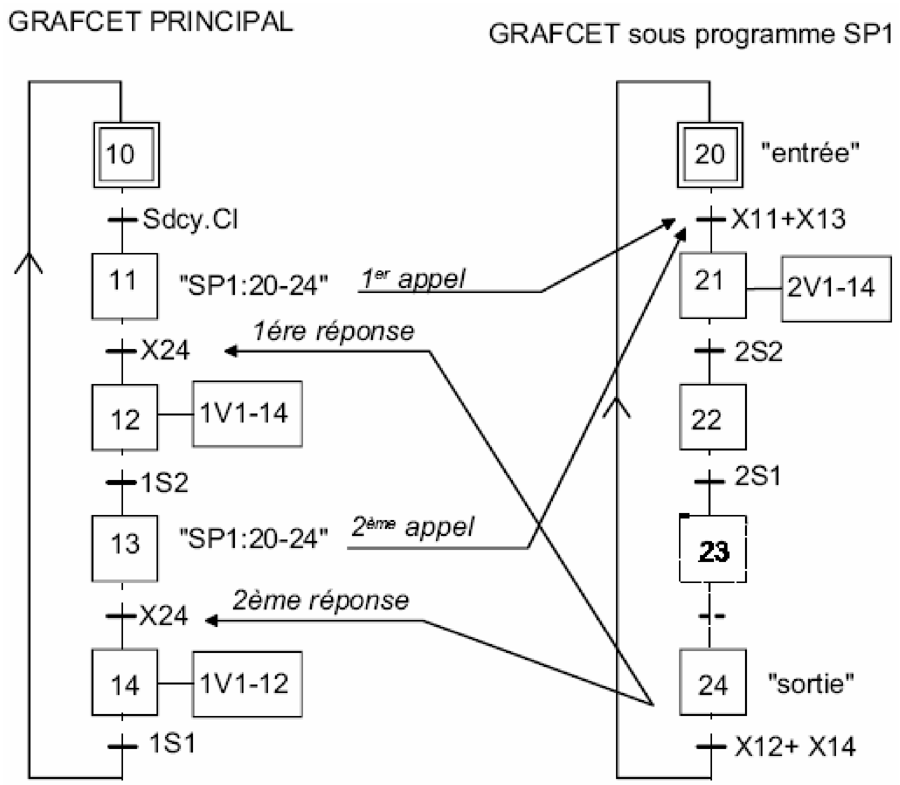


Figure 94: Task and sub-program based structure

9.17. GRAFCET: APPLICATION

This involves defining precisely the elements to consider in the description so as to determine the logic and event inputs/outputs enabling us to describe the GRAFCET receptivities and actions. It also involves determining all of the orders and reports, i.e. all the exchanges between the CP and OP.

9.17.1. Operating mode

It is possible to directly describe the complete operation of a small system, but this becomes inconceivable if the system is complex. In this case we need to adopt a problem segmentation study approach. The GEMMA tool (On-Off Modes Analysis Guide) provides an efficient analysis method by segmenting the problem into operating modes, and analysing each in turn.

In an automated system, GEMMA identifies the main operating modes with the following analysis order:

- normal production analysis,
- definition of stoppage in initial state,
- analysis of production initiation,
- analysis of production stoppage,
- failure analysis,
- initialisation analysis,
- analysis of other modes: checking, test modes...

In the creation of a GRAFCET, the operating mode it describes needs to be specified and observed.

9.17.2. Creating the structure

Depending on a system's complexity, a variety methods can be used.

9.17.2.1. Immediate identification of a GRAFCET structure

On simple systems, we can try to identify which of the basic structures (sequence, switchover, parallelism, repeat sequence...) is suitable, or if appropriate assembly of them might satisfy the specifications.

9.17.2.2. Behaviour analysis

A list of the different behaviours of the OP is drawn up (without duplication), we allocate a step for each one, and then we try to find the behaviour following each behaviour; in this way we can build up the GRAFCET "step by step".
For simple problems, this method can identify the basic structures to use.

9.17.2.3. Coordination of tasks

If the system is complex, it is best to divide it into sub-systems, analyse each sub-system, and then create a higher level GRAFCET with the aim of synchronising these sub-systems.

9.17.3. Actions carry-over

Previously determined output variables are then carried over.

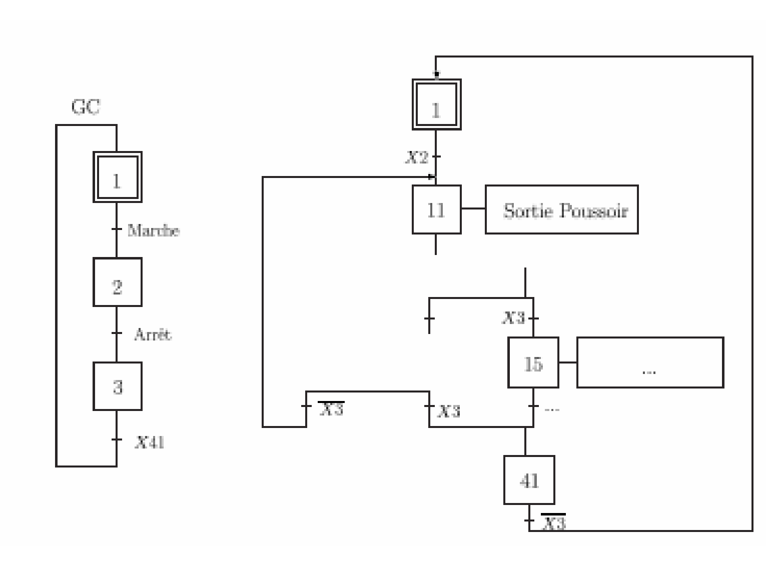
9.17.4. Carry-over/determination of receptivities

The receptivities are worked out from input variables and/or internal variables, or they are determined if need be by finding the necessary conditions for switching between states.

9.17.5. Initial state, initial situation, production initiation

When we reach this stage of the analysis, we need to define the initial state of the system: the state in which the system is before switching to normal production. Once this state has been defined, we will be able to specify the initial situation of the GRAFCET describing normal production. To initiate normal production, experience demonstrates that it is most efficient to create an upper level GRAFCET (generally known as GC: control GRAFCET) to enable the initiation of the normal production GRAFCET (GN), and then its stoppage.

9.17.6. System stoppage and return to initial state



The stoppage and return to initial state may be tricky to analyse. In fact the stoppage order may come at any time in the cycle, but the cycle in progress must finish so that the operative part returns to the initial state - on GPN that will be manifested by one or more "output" switchovers, some of which may have special sequences so as to return the OP to initial state.

Figure 95: Structure set-up, initial state

9.17.7. Task coordination structure

9.17.7.1. Introduction

The complexity of automated systems requires in their design a methodological approach based on top-down analysis procedures. This approach starts with as general as possible a description of the system, with the system broken down into a minimum of elements. Of the different functions to be ensured by an automated production system, it is the operative functions that achieve added value on the products. The technical and technological choices define a set of functional operations manifesting these functions. Based on a top-down analysis approach, appropriate division of these operations into tasks will reduce the elements for analysis, thereby minimising the complexity of analysis.

9.17.7.2. Characterisation of a task

A task is a functional grouping of a set of operations for which a start or initiation and an end are defined, in relation to a division criterion. Any operation belonging to a task is temporally and/or structurally disjointed from all operations of other tasks. There is no link between an operation within a task and an operation within another task (other than links defined by the task initiation and end)

9.17.7.3. Task representation using GRAFCET

GRAFCET representation of a task may take various forms:

- Sub-program, Standardised
- Task, non-standardised,
- Macro-step, standardised

Currently the macro-step concept is the most widespread and commonly used.

9.17.7.4. Methodology for drawing up a task coordination GRAFCET

1. Step 1: definition of various tasks and input/output definitions,

2. Step 2: finding prior and post conditions. For each task, we describe the task start and end transition rules.

   - Task T_i start transition rule, if task T_i start conditions satisfied, then do task T_i
   - Task T_i end transition rule, if task T_i end conditions satisfied, then authorise task T_j

3. Step 3: plotting of a graph associated with each task. Each task has an associated partial graph structured as follows: The initiation condition of task T_i, expressed by the end of task T_j is represented by a step bearing the number *ji* or even $j \longrightarrow i$. The end of

performance state of task T_i authorising task T_k will be represented by a step bearing the number *ik* or $i \longrightarrow k$.

4. Step 4: drawing up the task coordination GRAFCET.
To draw up the task coordination GRAFCET, we superimpose the steps with the same tags on the graphs associated with the different tasks. If non-functional steps appear, then they are eliminated.

9.17.8. Application / exercise

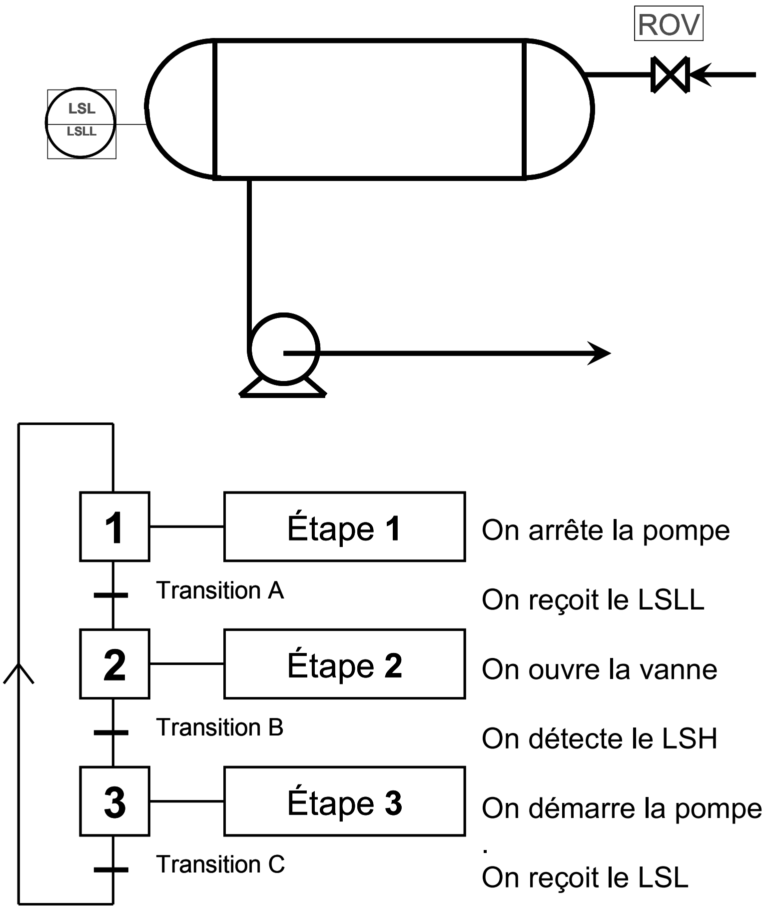


Figure 96: Simple process with GRAFCET

10. AUTOMATIC CONTROLLER DIAGRAMS

In its external part, the "hardware" part, automatic controllers use "ordinary" diagrams, i.e. simply the schematic diagram with the power distribution and control/command distribution

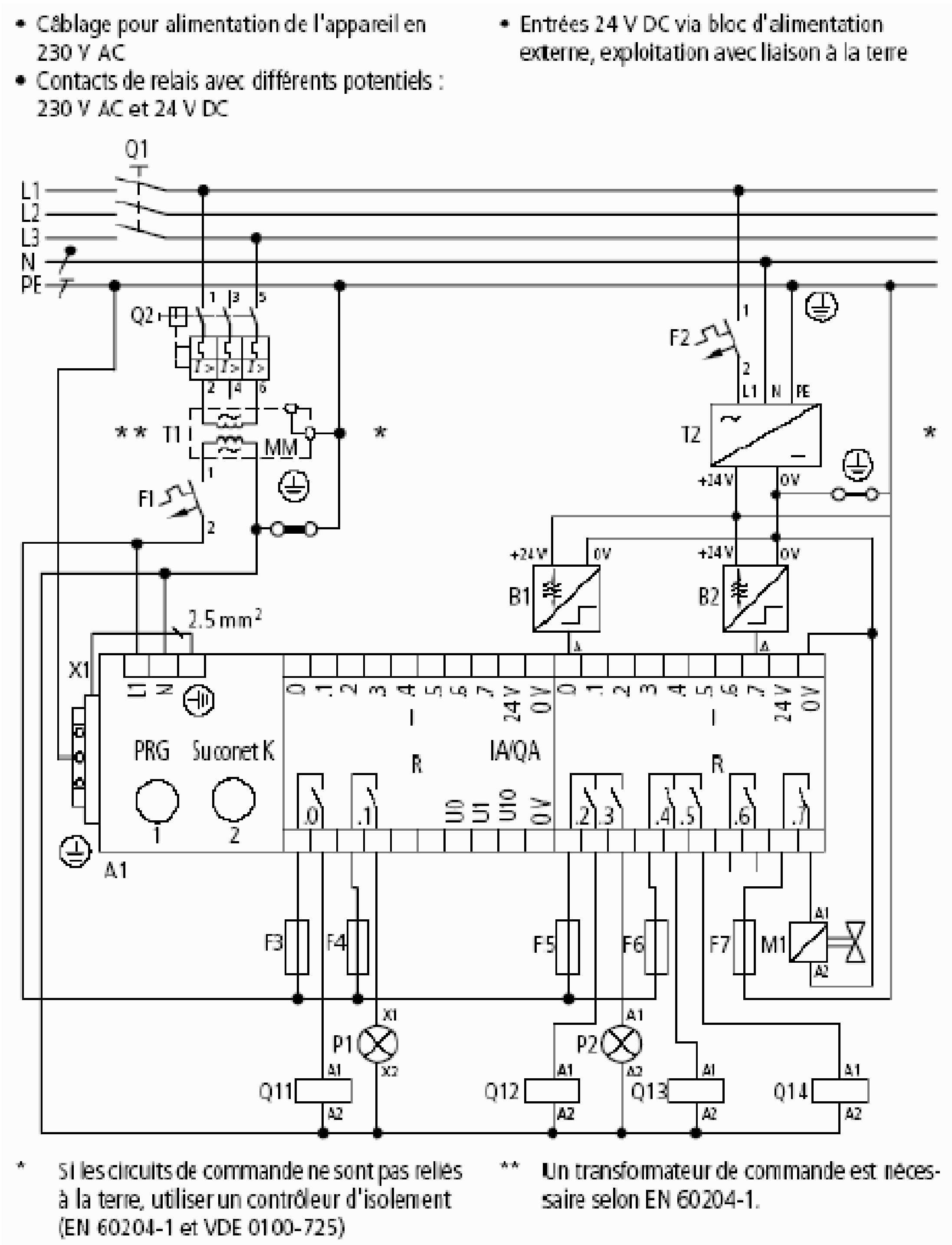
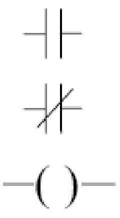


Figure 97: Example of supply wiring + inputs / outputs on a standard Moeller compact automatic controller

You have already looked at the symbols (contacts and external devices), so there is nothing special there.

As for the "LADDER" diagram, it will be looked at during the automatic controllers course

It is a graphic language, directly translating an equation or logic into an electrical diagram with special symbols



- Make contact
- Break contact
- Coil

The other symbols are dependent on the manufacturer, and are summarised in a block (a box or function) in which its role is explained (time-lag, clock, algebraic function, etc.)

In the automatic controllers / PLC course, there will be (a bit) more to say.

11. FLOWCHART – LOGIC DIAGRAM

A type of plan / diagram / sequence primarily used for describing a troubleshooting procedure

They manifest a logical sequence of events or checkpoints, indicating the ‘directions’ to follow or initiatives to take

Below are 2 examples of a ‘logic diagram’, both in a troubleshooting sequence

NB: not to be confused with the logic diagram with logic gates (which is the ‘true’ logic diagram): in this case we will rather talking about a flowchart, the term ‘logic diagram’ is to be frowned on in this type of application

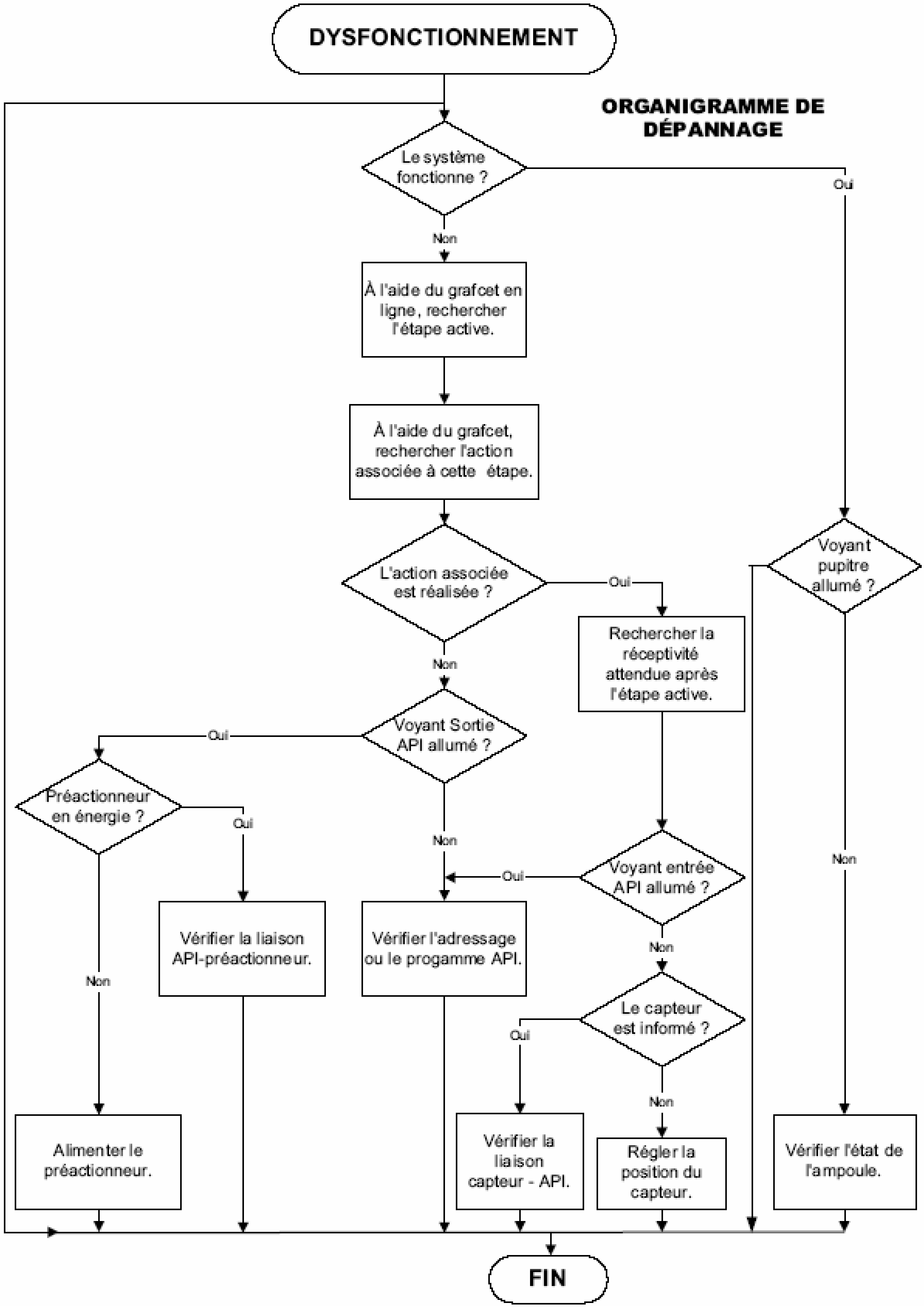


Figure 98: Standard troubleshooting flowchart

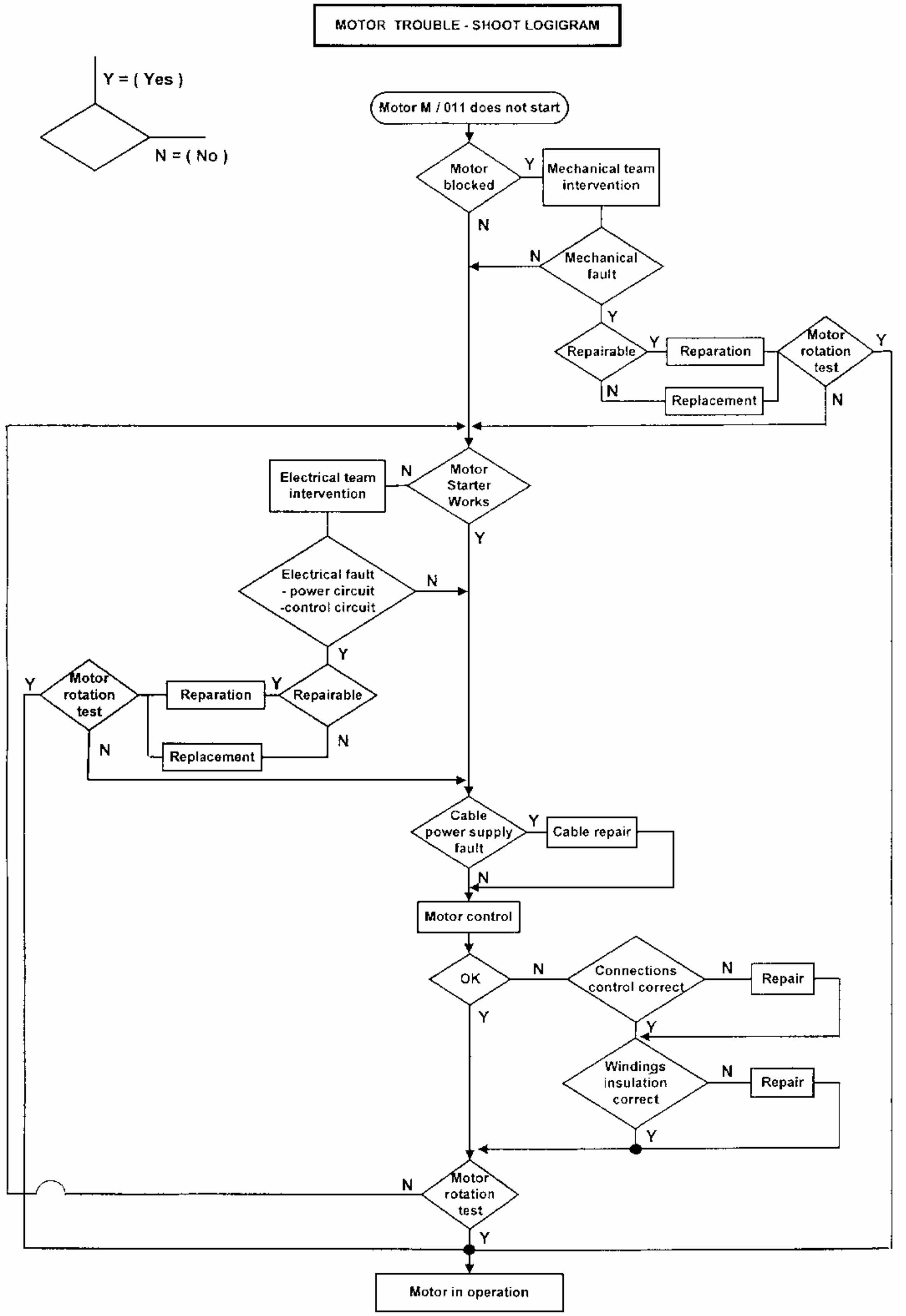


Figure 99: Motor trouble shooting logic diagram

12. DOMESTIC DIAGRAMS

Or the creation of plans and diagrams for blocks of flats, houses and offices.

Some might claim that these diagrams are not an everyday occurrence in our industry, something that does not concern us……

For those who claim to be electricians, who have a pretty good knowledge of industrial installations, a good level, a good degree and good experience (in industrial electricity), I find it a shame that they do not know the standards of installations for a simple domestic current socket…

These will be the same sort that scorn HVAC because they have never been confronted with a 'serious' air con installation.

So please show 'humility' with all disciplines of electricity (and instrumentation, electro-mechanics); any specialisation is worthy of consideration…, including your own if you already have one, and that of others for the future.

These domestic diagrams can be found not only in the 'tertiary' sector, but also in 'industry' when building offices or even accommodation within an industrial complex. You may also consider these diagrams as a support for personal installations …..

The primary objective of this section is to give you a tool to make you 'purveyors / ambassadors' for "sound electrical installation".

You are an electrician, and you work on a Total site, so you have a pretty good knowledge (or at the very least sufficient) of the field of electricity.

Off-site, around you, you may see electrical installations not observing the standards, and even set-ups that make your hair stand on end (it's often happened to me). If there has been no training or information provided, it's probably normal. But it's your role to spread the 'word', explain how things should be done; so use this section outside the Total site: there's no problem, that's what it's for.

12.1. STRUCTURE OF A DOMESTIC INSTALLATION

12.1.1. Supply

This electrical installation consists of several elements, the purpose of which is to convert electrical energy into another form of energy (light, heat, cold, mechanical energy).

An electrical installation comprises:

- Electrical energy supply from a distribution network (depending on the supplier, and country).
- Monitoring apparatus (energy meter).
- Protection apparatus (breaker, fuses, etc.).
- Control device (switch, push-button, etc.).
- Application devices (lamp, radiator, etc.).
- Electrical conduits connecting everything together (conductor, sheath, sleeves, etc.).
- Structural accessories (junction, branch and housing boxes, distribution switchboards, etc.

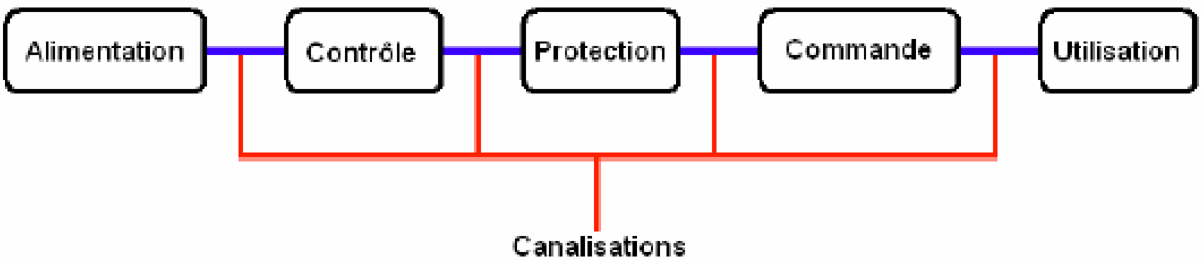


Figure 100: Structure of domestic distribution

For domestic supplies (in houses), there are two possibilities from the distribution network:

- Single-phase (often used for domestic installations (one phase and neutral).
- Three-phase (distributed when a high power level is required (three phases and neutral).

The main characteristics of an electrical supply network are (in France and Europe)

- frequency 50 Hz.

- Supply voltage:

220 / 230 V = Voltage between 1 phase and neutral.

380 / 400 V = Voltage between phases.

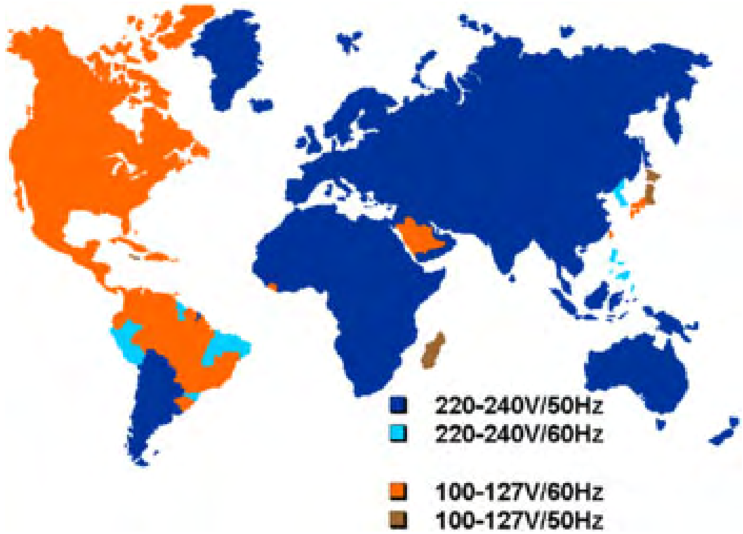


Figure 101: Domestic distribution worldwide (voltage between 2 wires)

The voltage and frequency values differ between countries

12.1.2. Diagrams in domestic settings

12.1.2.1. Architectural plan

This plan represents the room or residence, with its dimensions.

On this representation, we distinguish the location of:

- The distribution / protection switchboards (by accessories)
- Sockets (current, telephone, television, etc.),
- Lighting points,
- Control points,

And using standardised symbols, in accordance with the specifications, the connections between the control points and controlled device are represented by dotted lines.

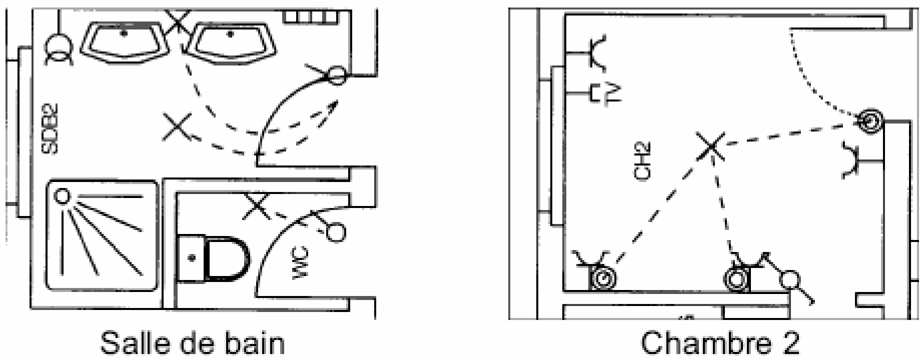


Figure 102: Architectural diagram in individual rooms

If a current socket is controlled by a switch, the connection is represented

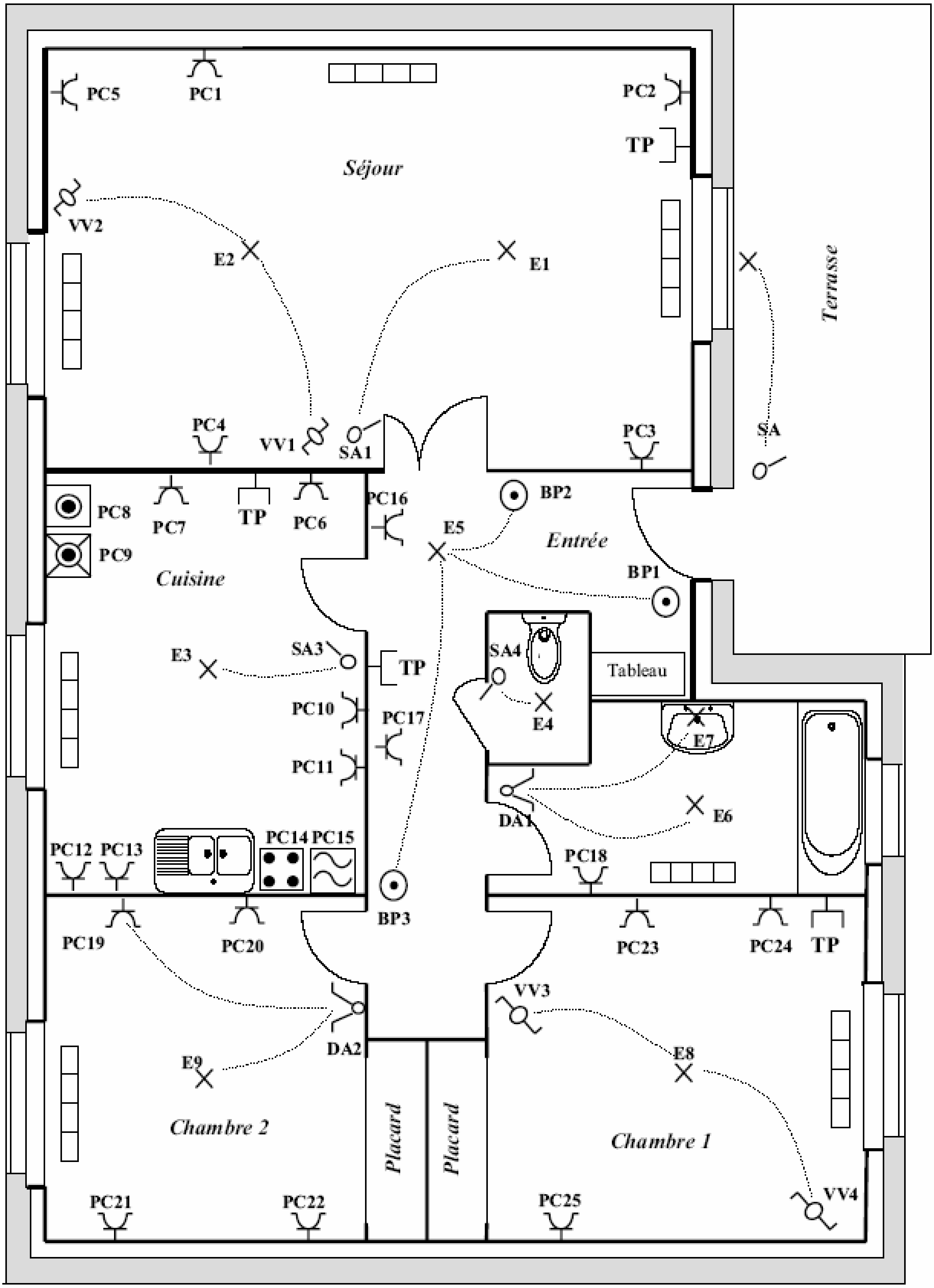
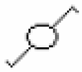
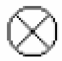
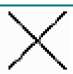
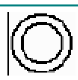
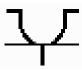
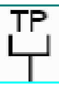
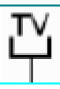
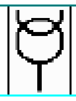
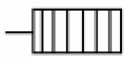
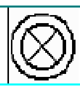


Figure 103: General architectural diagram of a residence

12.1.2.2. Exercises

22. As you know the symbols from the previous course (MN-SE010), identification in the table below should be child's play…

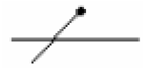
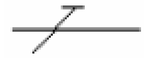
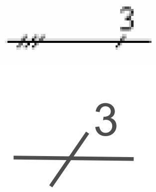
    And even if certain symbols may not (apparently) be familiar, you should still have no problems. As for the description, the terms used, things might be slightly different.

Symbols	Your answer
	
	
	
 or 	
	
	
	
	
	
	
	

12.1.2.3. One-line (architectural)

This representation, based on the general architectural plan, consists of the location of devices and conduits, on which the number and type of conductors are specified. (Review the symbols)

The conductors are represented by an oblique line on the conduit.

	If it is a neutral conductor, a dot is positioned at one end of the oblique line.
	Protective conductors are represented with a line at the end of the oblique line
	Other conductors are represented by a single oblique line.
	If there are several conductors of the same type, we can only plot one line and indicate beside it the number of identical conductors
	Different types of conductors in the same conduit are indicated on the same symbol

Example: let's take the architectural diagram of a room

Draw the one-line diagram of the lighting for room 1

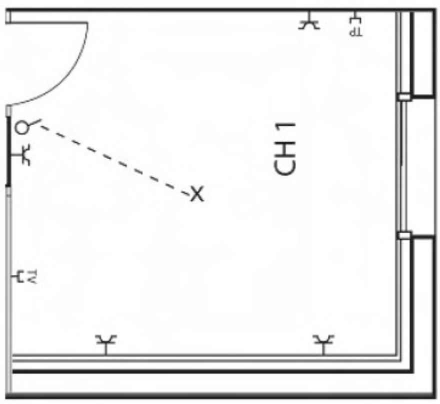
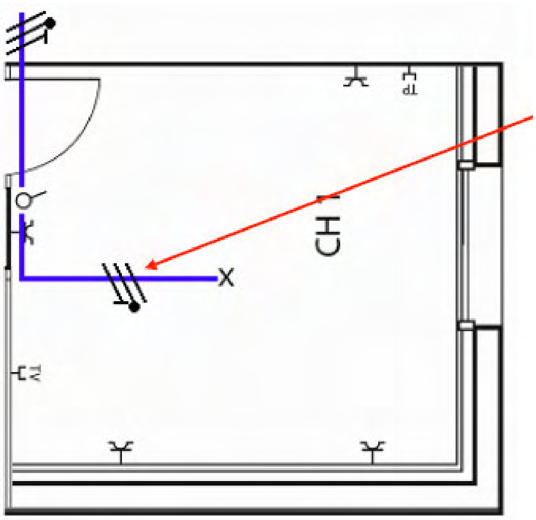


Figure 104: Architectural diagram for room 1



On this diagram
we can distinguish that we need a phase, a neutral and a protective conductor (earth).

Figure 105: One-line architectural diagram for room 1

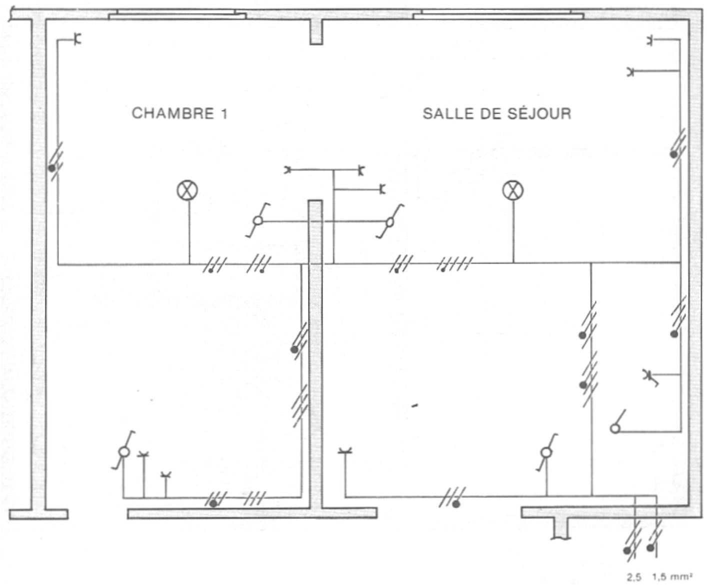
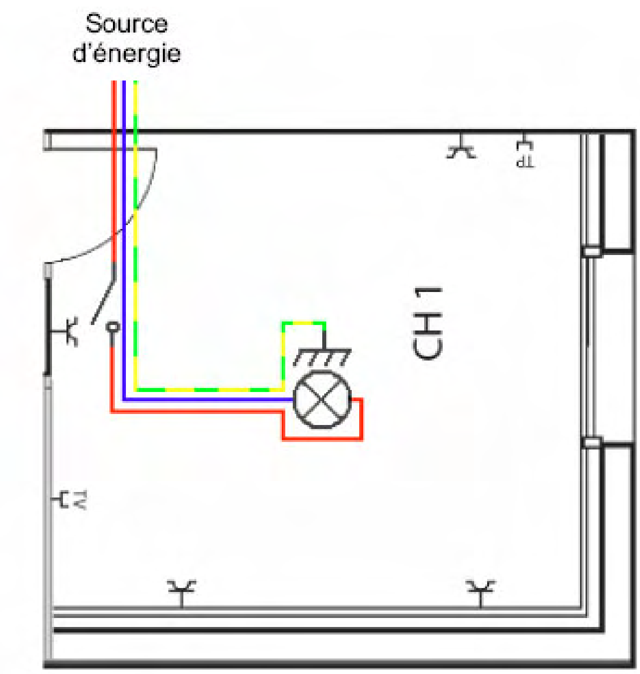


Figure 106: Complete one-line architectural diagram

12.1.2.4. Wiring and connection / multi-line diagram

This diagram tells us how many wires need to pass through the conduit, and their colours (*possibly, as the distribution has an implicit wire colour, see special course*). These wires will of course be at the same locations as the conduits defined in the one-line diagram.



The symbols used for contacts are identical to those in 'conventional' diagrams.

With room 1 again, here is the multi-line diagram version

Figure 107: Architectural multi-line diagram for room 1

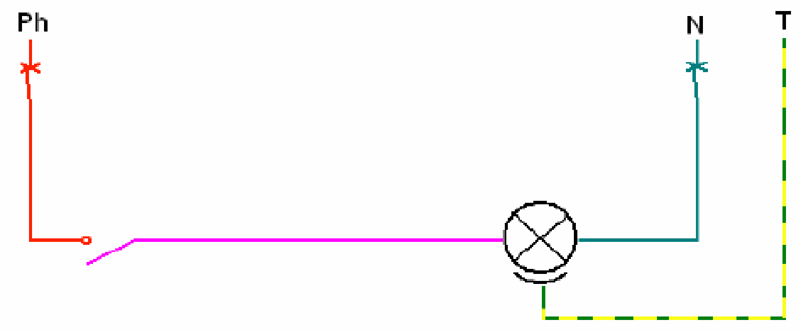
Regarding the colours (standardised): the phase wire is red, neutral is blue and earth is green/yellow

As with "other wiring and connection diagrams" in industry, this diagram will quickly become overloaded and difficult to read if we need to cover all the circuits in a residence…

12.1.2.5. Schematic diagram

This representation lets us see the electrical connections.

This just about takes us back to the principle of the "conventional" industrial diagram representation



Again, here is the lighting circuit for room 1 with single breaker protection

Figure 108: Schematic diagram of room 1

Note the use of the colours:

- Red for phase from the breaker
- Blue for neutral (back from the lamp
- Green – yellow for earth
- The "internal" links, e.g. between switch and lamp, may have other colours, including red (as blue is reserved for neutral and green – yellow only for earth) (green and yellow separately are also prohibited

All these diagrams are 2 wires (+ earth):

- Protection is single-phase by fuse or breaker with ‘Phase + Neutral’ supply.
- Protection is two-phase (on the 2 ‘wires’) with 2-phase supply
- Cut-off is bipolar in all cases (on the 2 wires)

12.1.2.6. One-line diagram

Let's take the same type of diagram as in industry, demonstrating the circuits and protections from the distribution switchboard, following the general principle of the figure below

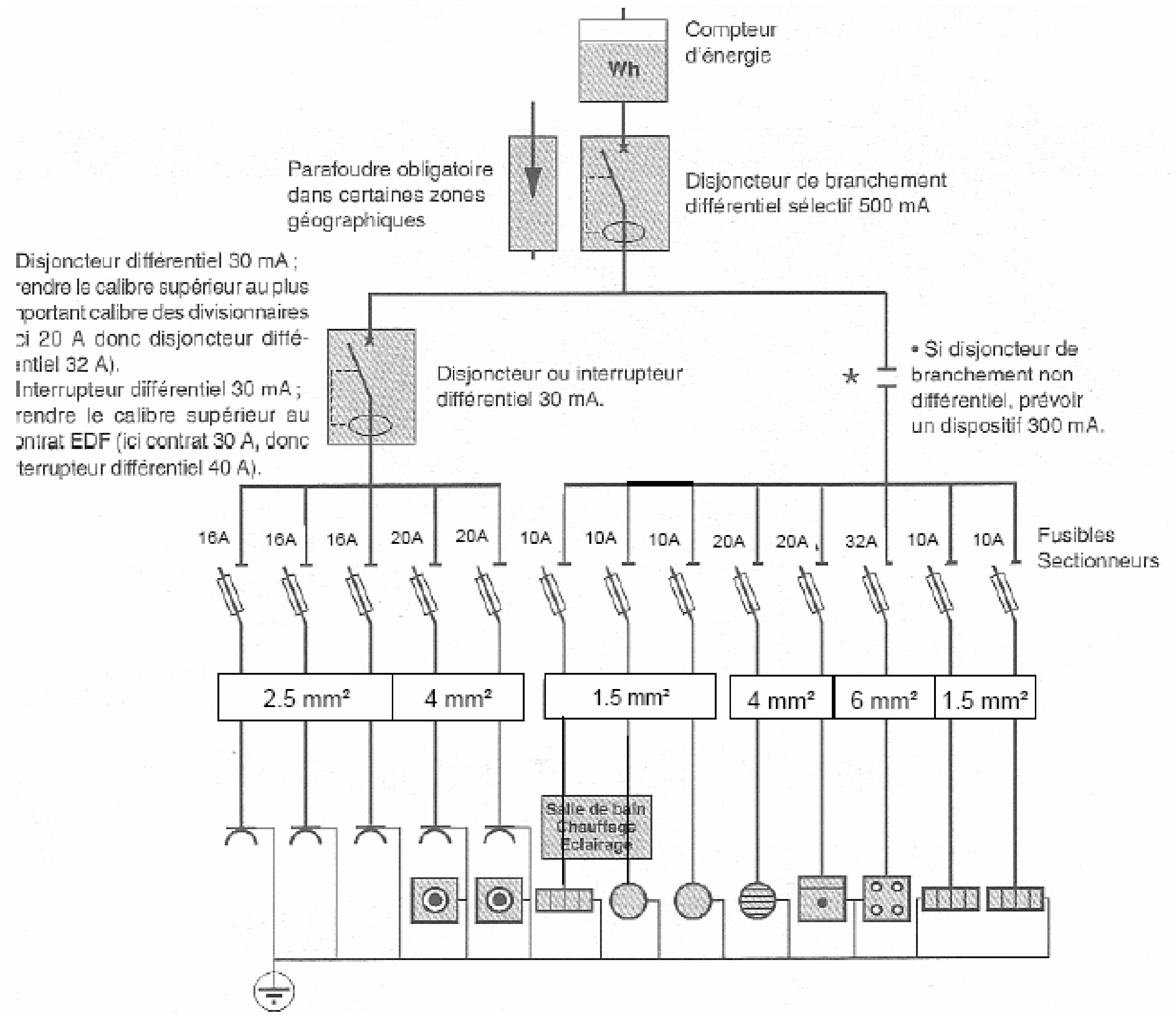


Figure 109: Schematic diagram of one-line distribution / protection

Confirmation of note in the previous sub-section:

- In old switchboards, and old distribution systems, the protection (on the main switchboard) was in single-phase only; protection and opening of phase circuit only, with neutral remaining constantly connected on the connection 'strip'.
- In new installations, cut-off must be bipolar: phase and neutral are opened at the same time, whether an isolator, fuse or breaker is used. NB, neutral is never protected, there are no fuses or trips on the neutral conductor.

- ***In 2-phase distribution, there is no discussion; both the cut-off and protection are bipolar on the distribution switchboard.***

  As for the switch, in this case, it is supposed to be bipolar too! That is why we use relays, contactors, remote switches (in the switchboard) with safety voltage on control switches / pushbuttons with 220V between phases.

  This particularly applies to industrial installations; lighting and current sockets are (individually) supplied with 2 wires, but from a three-phase 220V network. There are good reasons not to have distributed neutral. (Electrical safety course)

12.2. DIFFERENT TYPES OF CIRCUITS

We have already looked at the various types of diagram, so it ought not to be (too) difficult to read them if they become more complicated through a number of circuits. With a little application of the principles, you should be able to draw up these diagrams yourselves without any problem.

Let's look at the various applications that we may encounter in domestic distribution

The installation and design standards are looked at in the course 'Domestic distribution', at this point we only need to be able to read and understand a diagram. In domestic distribution, the installation starts from the customer breaker fitted (in principle) by the distribution network entity (EDF in France).

From this customer breaker, sub-distribution systems need to be set up with protectors and bipolar cut-offs (breakers and/or fuses). For now, just remember that a 30 mA differential protector (differential switch or breaker) is required for all current sockets, and a 300 mA protector for lighting circuits (500 mA should be eliminated if not already done).

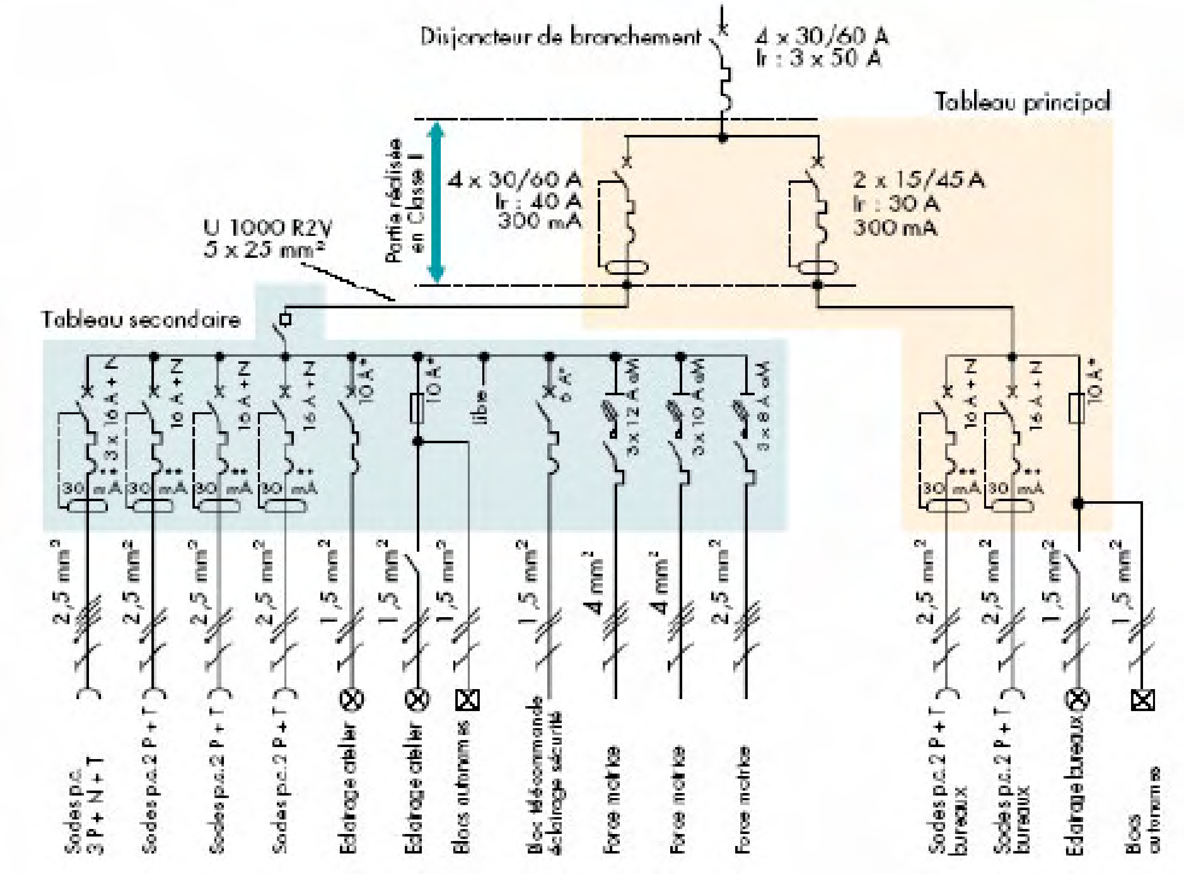


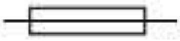
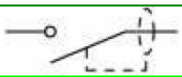
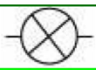
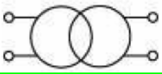
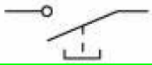
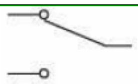
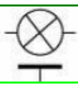
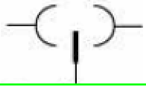
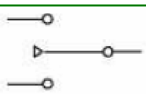
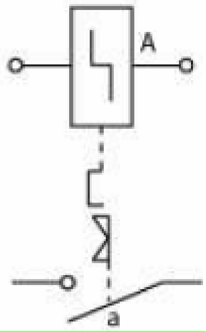
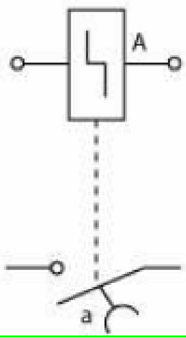
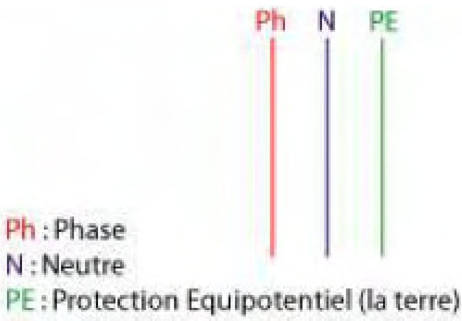
Figure 110: Principle of one-line distribution / protection diagram 2

The example above is semi-domestic / semi-industrial, and you will (definitely) come across it on-site. Note the differential protectors
And now for typical diagrams

12.2.1. Exercises on symbols

Let's run through symbols / diagram in the field of architecture.

23. Identify these symbols taken from a diagram

Symbols	Your answer	
		
		
		
		
		
		
		
		
		
		
		
		

12.2.2. One-way switching

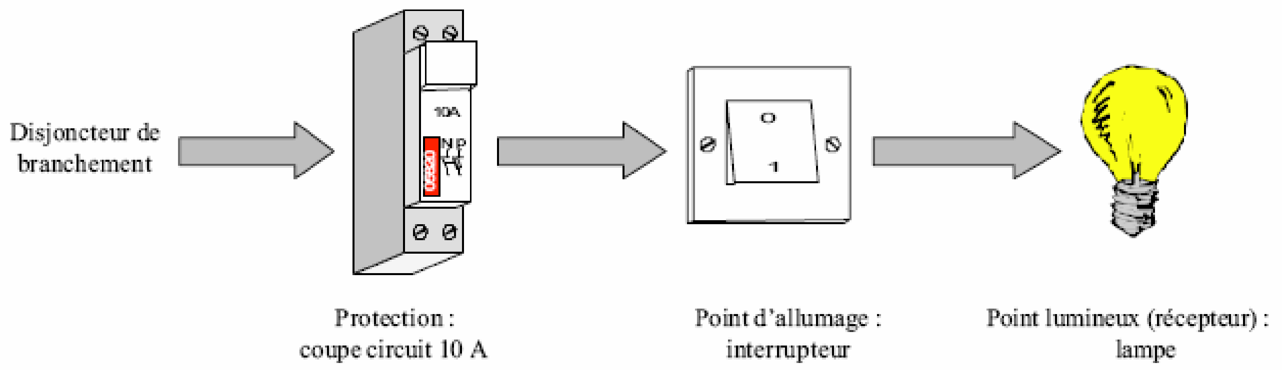


Figure 111: One-way switching in 3D

Below is a schematic of one-way switching, with a single lighting point and "lights in parallel" version.

In domestic applications a switch can control a current socket

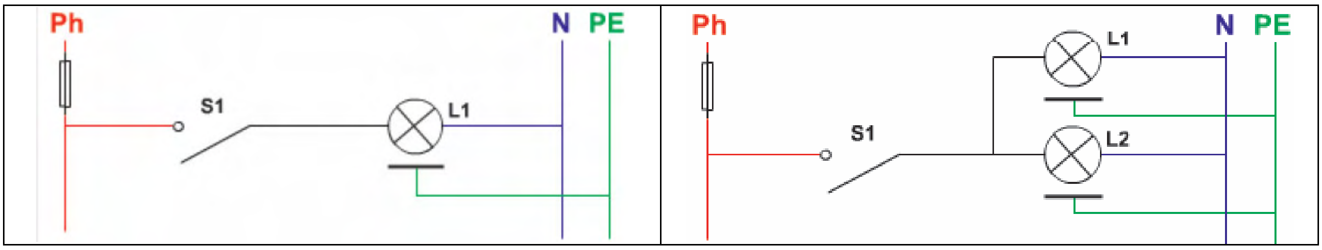


Figure 112: One-way switching in schematic form

12.2.3. Two-gang one-way switching

This enables us to switch on or off the lights together or separately, from a single point.

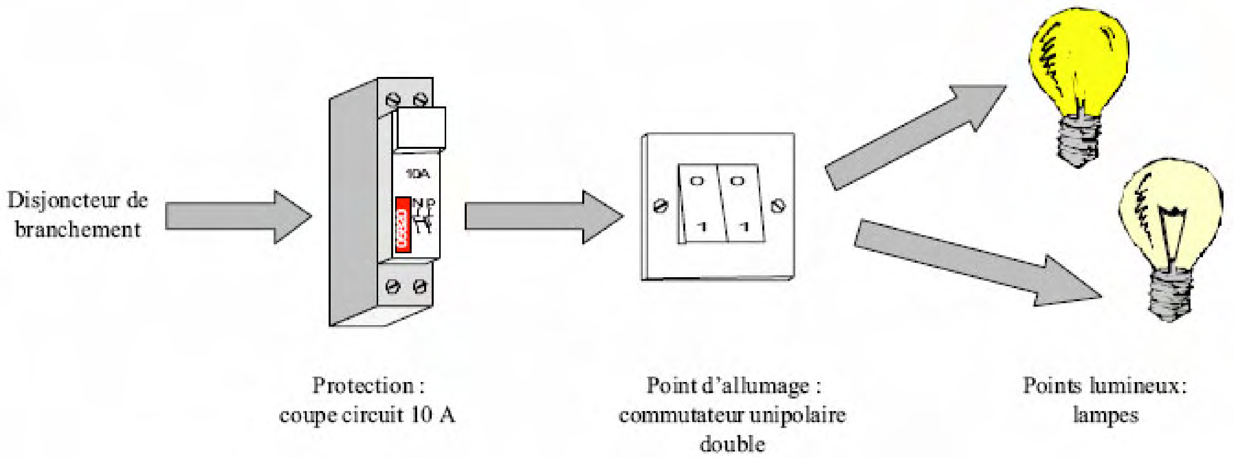


Figure 113: Two-gang one-way switching in 3D

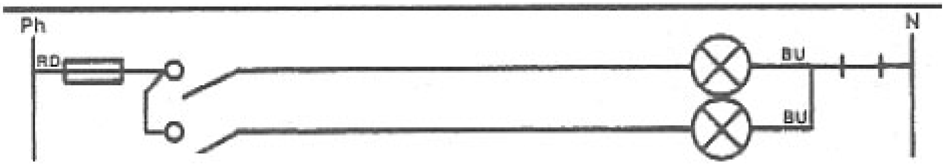


Figure 114: Two-gang one-way switching in schematic form

12.2.4. Two-way switching

This controls switching on and off of lights from two different points: and only from 2 points. If we want to add additional control points, we will need to add two-pole intermediate switches, which are no longer used, as the remote control switch (and pushbuttons) have replaced this type of set-up (with over 2 controls for two-way switching).

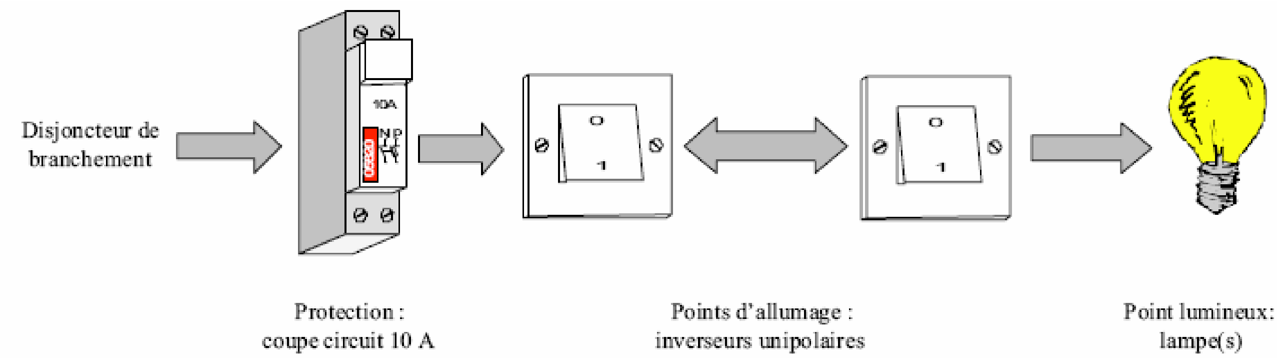


Figure 115: Two-way switching set-up in 3D

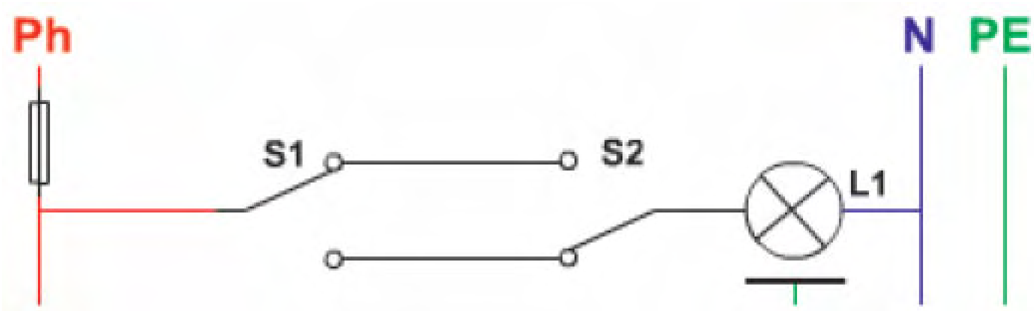


Figure 116: Two-way switching set-up in schematic form

12.2.5. Circuit selector switch

Choosing between circuits

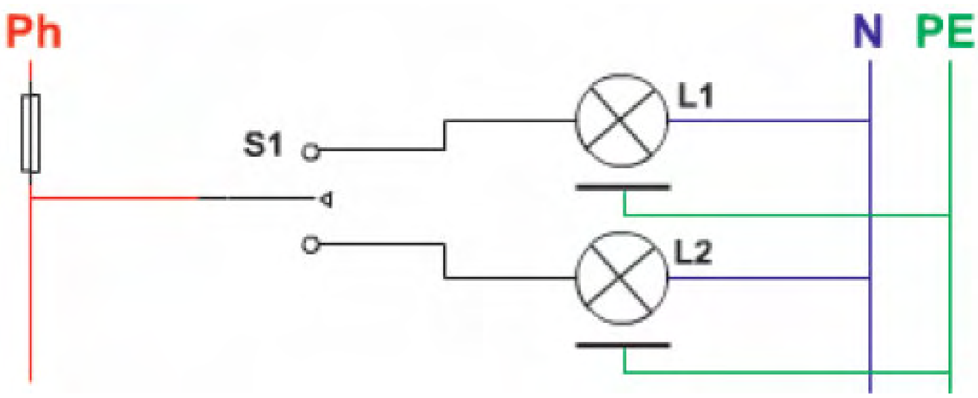


Figure 117: Selector switch in schematic

12.2.6. Remote control switch

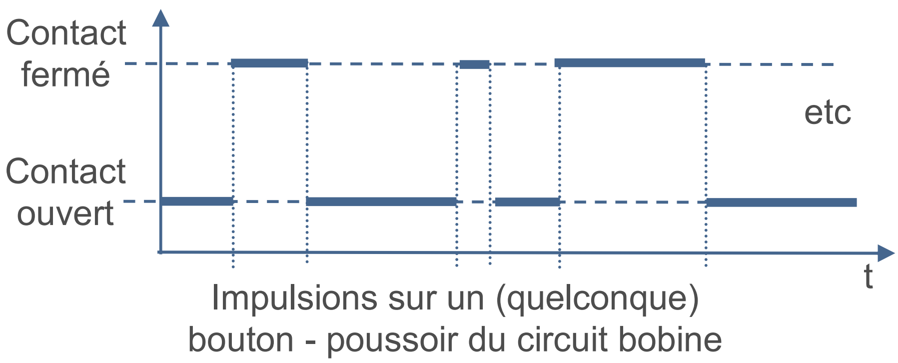
A remote control switch consists of a coil, one or more contacts and a mechanical system memorising the position of the contact.

A remote control switch set-up comprises 2 circuits:

- The control circuit with the coil and pushbuttons
- Used with the contact of the remote control switch (relay) on lighting "power circuit"

Operation

- One press (with pushbutton) on the coil closes the contact, and keeps it closed
- Another press opens the contact



And so on, with every press the contact changes state

Figure 118: '0' and '1' sequence of a remote control switch contact

A remote control switch is installed when there are at least three light switch-on points. E.g. A corridor, with *just 2 control points, a two-way switching system is more profitable (with single-phase).*

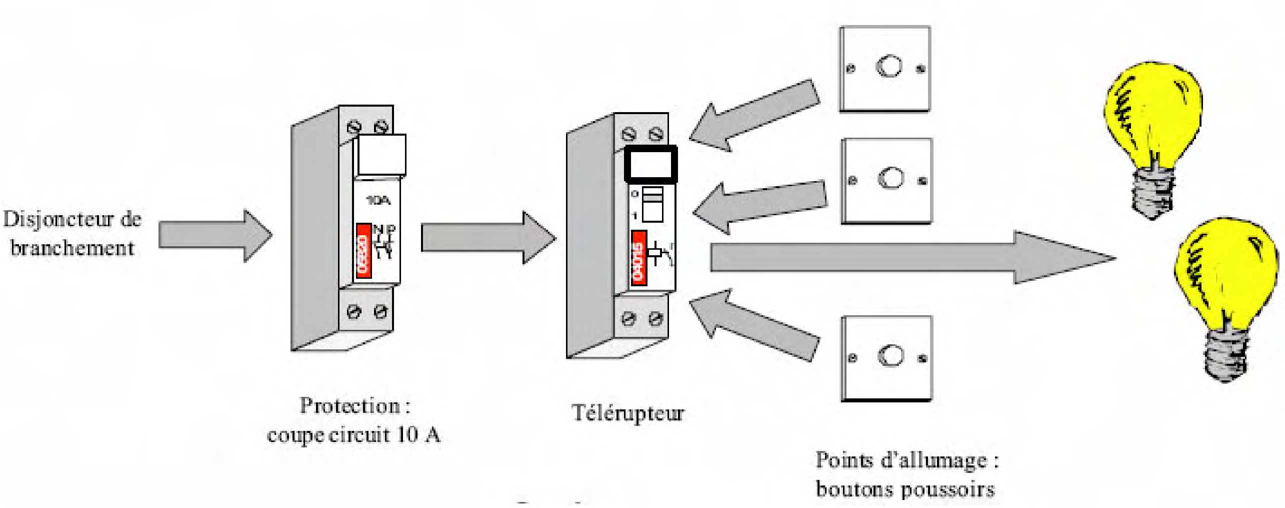


Figure 119: Remote control switch set-up in 3D

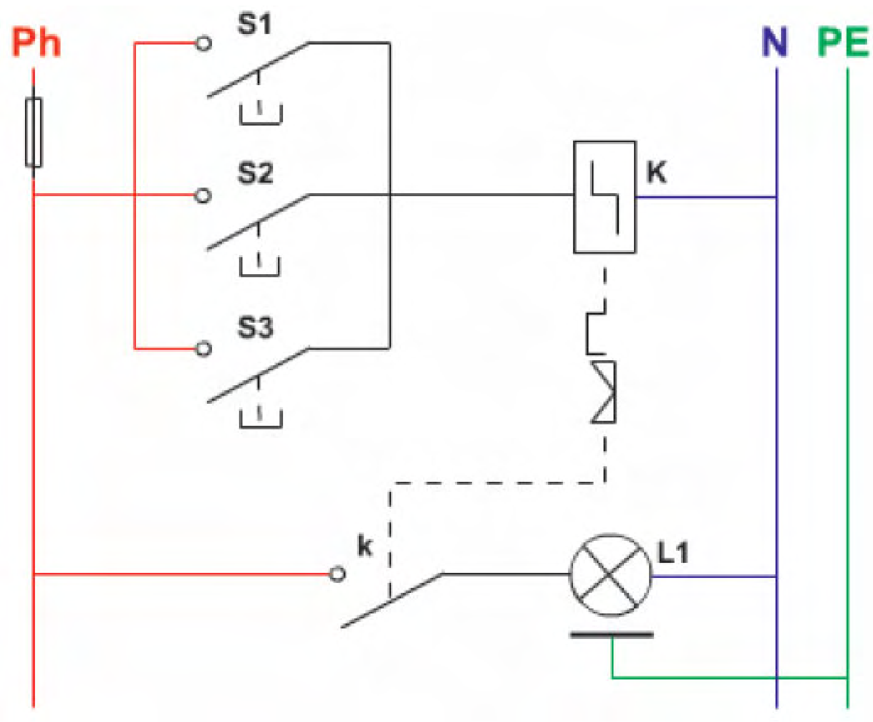


Figure 120: Remote control switch set-up in schematic form

The set-up may have a control circuit at a different voltage to the 'power' voltage on lighting devices. Generally this voltage is a safety voltage at ELV (Extra-Low Voltage), supplied by a transformer

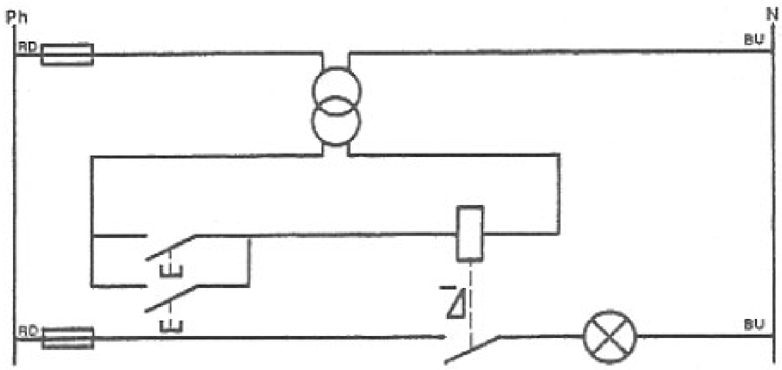


Figure 121: Remote control switch set-up in schematic form with a transformer on the control

12.2.7. Timer

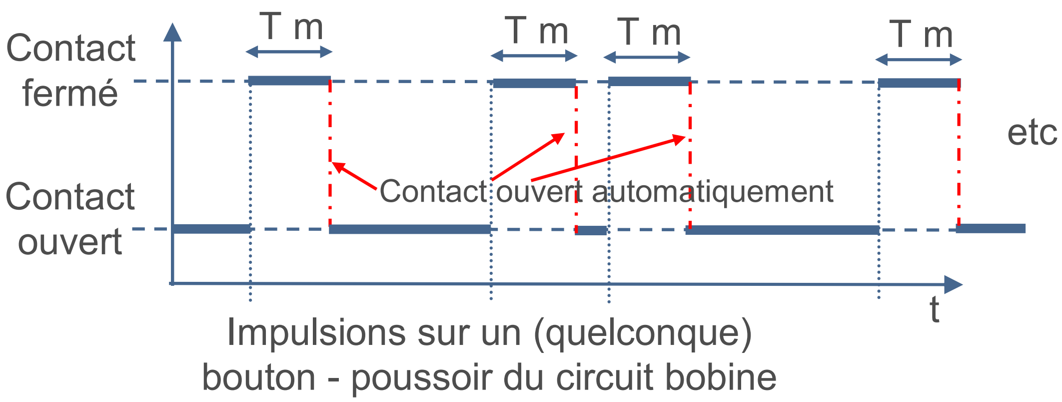


Figure 122: '0' and '1' sequence of a timer contact

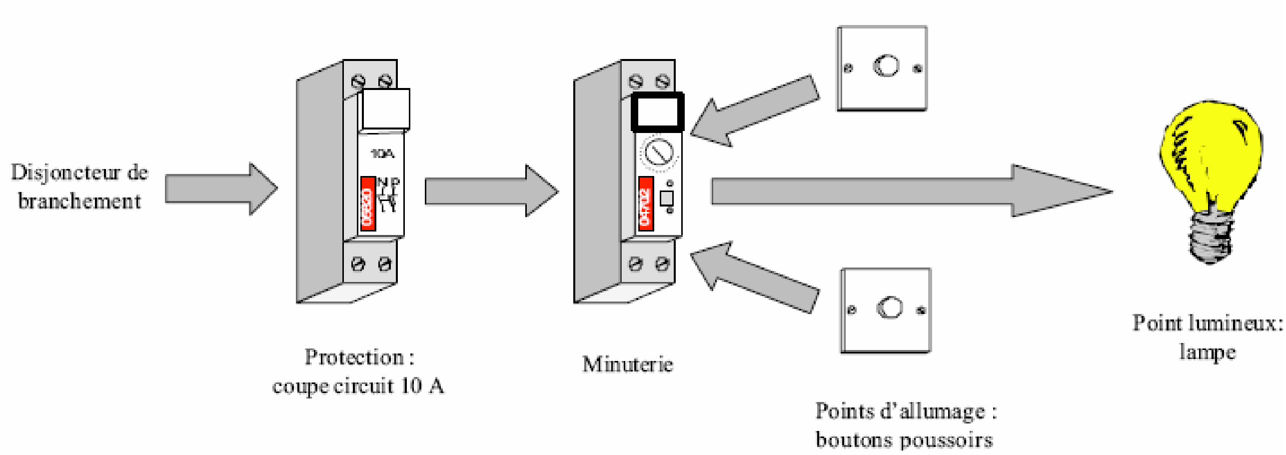
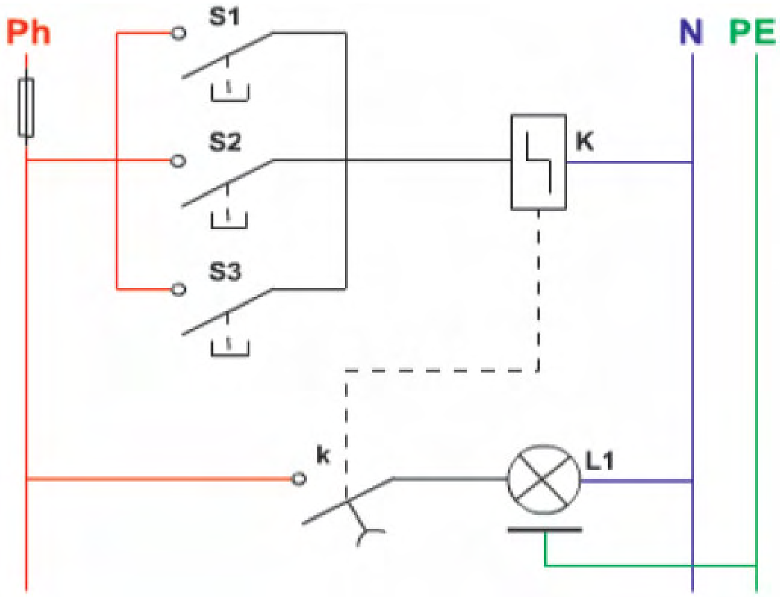


Figure 123: Timer system in 3D

A timer is installed if we want automatic switch-off of one or more lights.

Operation

Pressing one of the switch points (pushbutton) activates one or more lights for a pre-determined time Tm. Switch-off of the lights is automatic.



A timer offers the same advantages as a remote control switch in terms of the number of control points. The difference lies in the fact that the contact ‘K’ is time-lagged. So a single press on one of the contacts S1, S2, S3, is required to engage contact ‘K’ and activate the timer.

Figure 124: Timer set-up in schematic form

Once the time has elapsed (time setting made by user), contact ‘K’ disengages. The dotted line represents the link between the coil and contact.

There is a difference in operation that you might have noticed:

- When we press on a pushbutton, a time-lag restarts its cycle for the initial total time setting
- Pressing a pushbutton when the timer is active has no effect; the lighting will still be cut at the end of the pre-set time.

Whether reinitialisation is effective will depend on the type of wiring

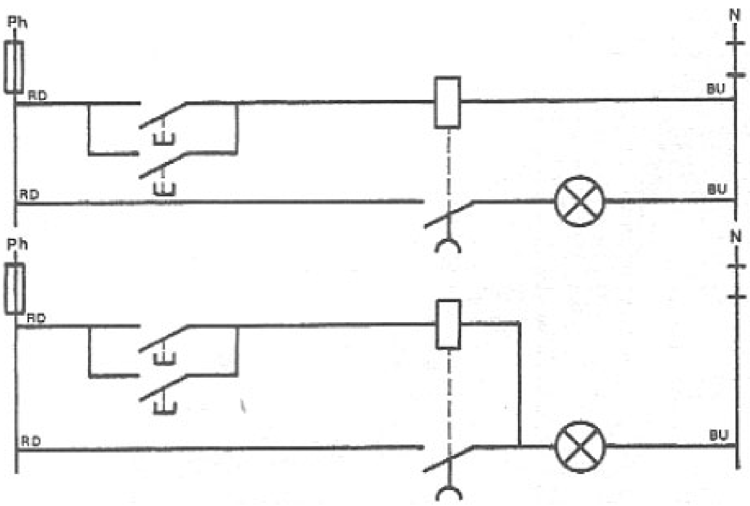


Figure 125: Timer set-up with reinitialisation (top) and without reinitialisation (bottom)

Compare these wirings

With the top set-up, the coil is constantly live; when we press a pushbutton, the time lag starts over;

With the bottom set-up, the voltage across the terminals of the coil is only effective at the first command. While the contact is closed, there is no possibility of voltage (engagement) across the coil terminals.

12.2.8. "Fluorescent" light set-ups

Below are some typical wirings for different types of gas illumination tube, which we should by rights call "*electric discharge in low-pressure gas tube"……*or more simply "luminescent tube". This gas is not fluorine, and even less so neon in conventional tubes. *See 'lighting and sockets' course.*

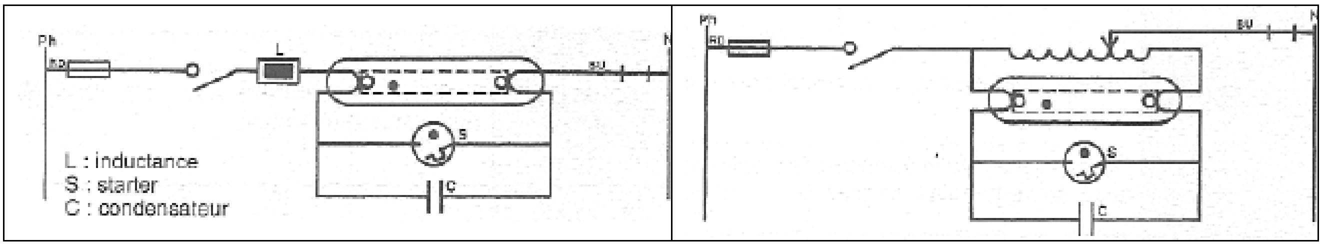


Figure 126 : Tube with 'self ballast' (inductor + starter + capacitor with/without auto-transformer

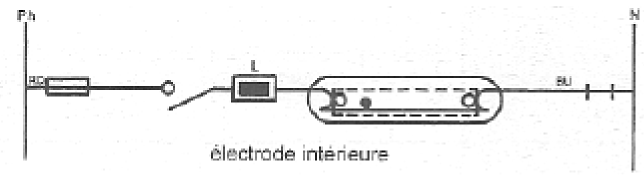
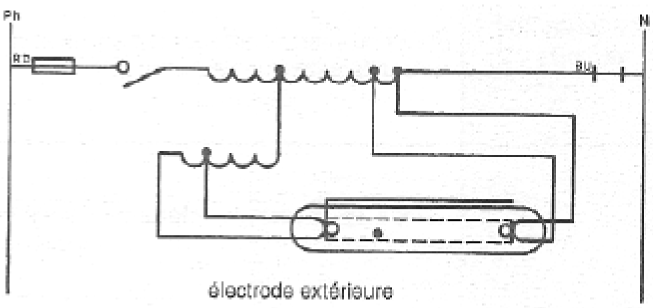


Figure 127: 'Quick start' type tube without 'warm-up'

Figure 128 : 'Quick start' type tube with 'warm-up' – with auto-transformer supply



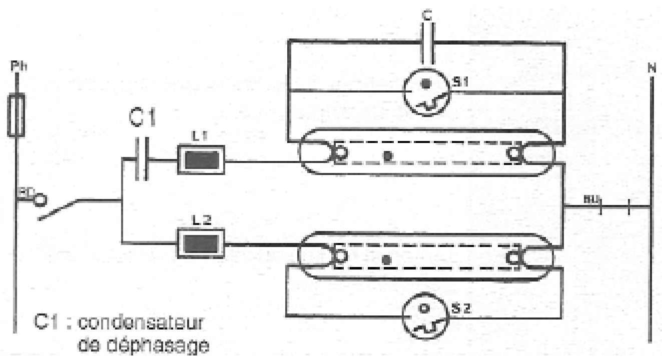


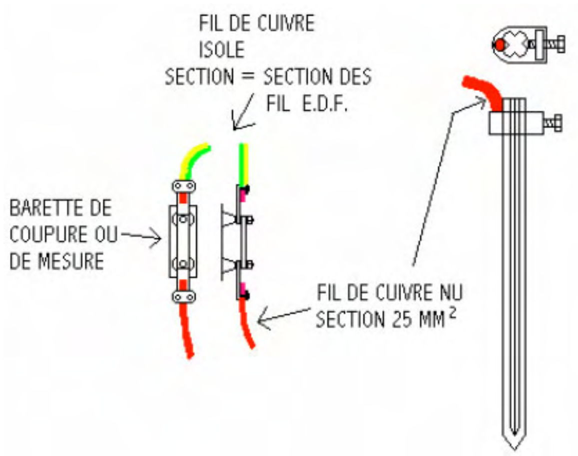
Figure 129: Double tube set-up to prevent stroboscopic effect

12.3. APPLICATION

Some advice and recommendations on diagrams and connections for your own installation (off-site….) ***while observing the rules of electrical safety …***

12.3.1. Earthing

Earthing is reviewed in the 'domestic electricity' course. We will just look at the principle here to remind ourselves – an essential part of installation, which is not necessarily indicated on all domestic diagrams!



The earth circuit starts with contact with real earth. This contact is provided via an earth rod. This comes in different lengths, the choice of which depends on the type of soil in which it is fixed. For heavy (argillaceous) soil a length of 1.20 m is sufficient, but for back-filled soil, we need a longer length so as to increase the contact surface area.

Figure 130: Domestic earthing

The earth electrode and circuit are connected to the cut-off strip by a bare copper wire with cross-section 25 mm².

The earth rod may be replaced by a bare conductor (25 mm² Cu) in the building foundation pit

12.3.2. Earth distribution in residences

An insulated green/yellow wire with the same cross-section as the supply wires (depending on the supplier) leads back to the distribution switchboard from the cut-off bar. A 2.5 mm² green/yellow wire runs from the switchboard to all metal masses in the bathroom, including door jambs and window frames, if they are metal or alloy.

There is also the main equipotential line running out from the switchboard. This is the line connecting the water and gas inlet pipes.

Its cross-section is 1/2 that of the supply wires.

For a 16 mm² supply wire (16/2=8), as there is no 8 mm² wire, we go to the next cross-section up, i.e. 10 mm².

All the circuits start out from the customer switchboard. They all have an earth wire of the same section as the corresponding circuit.

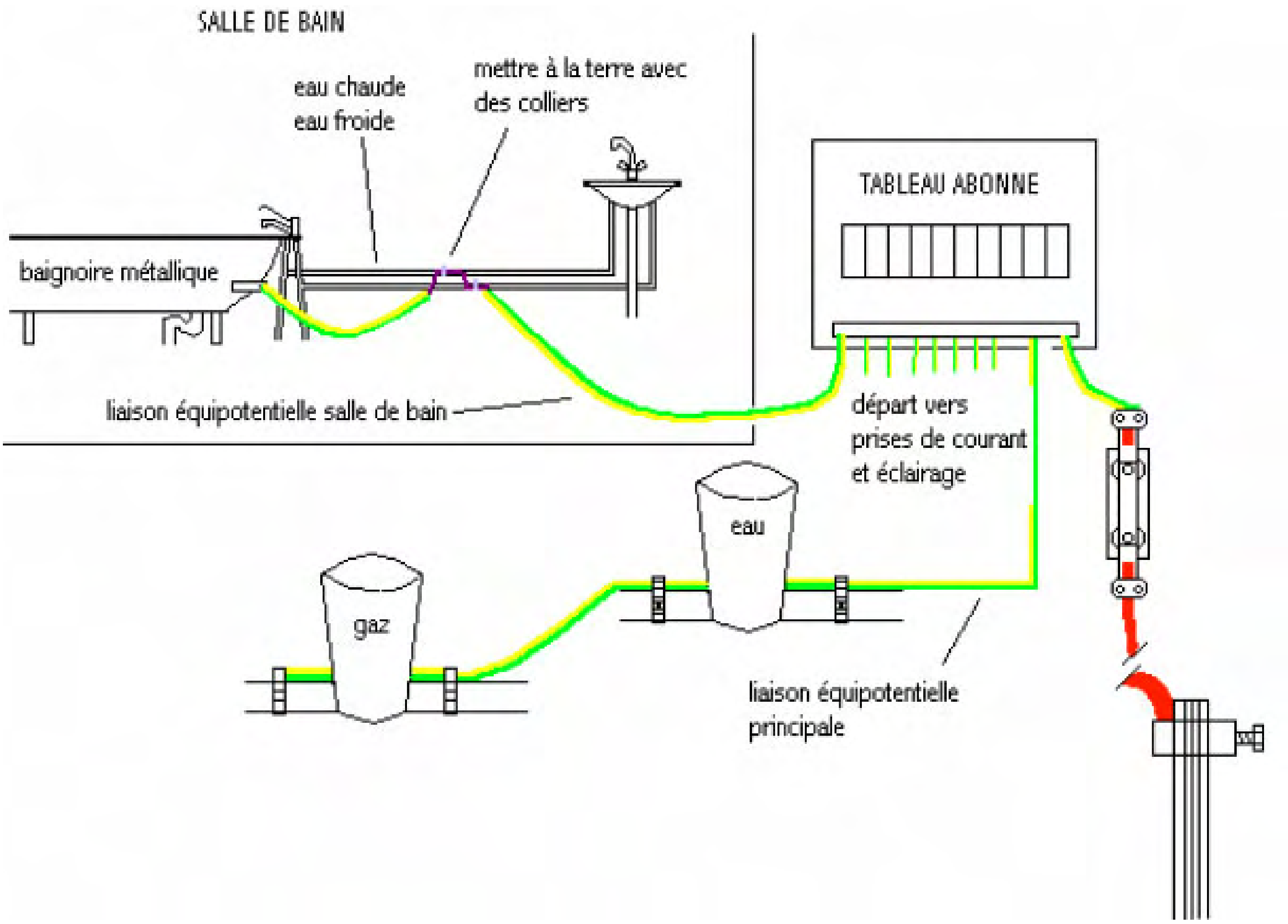


Figure 131: "Equipotential" earth distribution, for a house

12.3.3. Distribution switchboard

Or "customer switchboard"

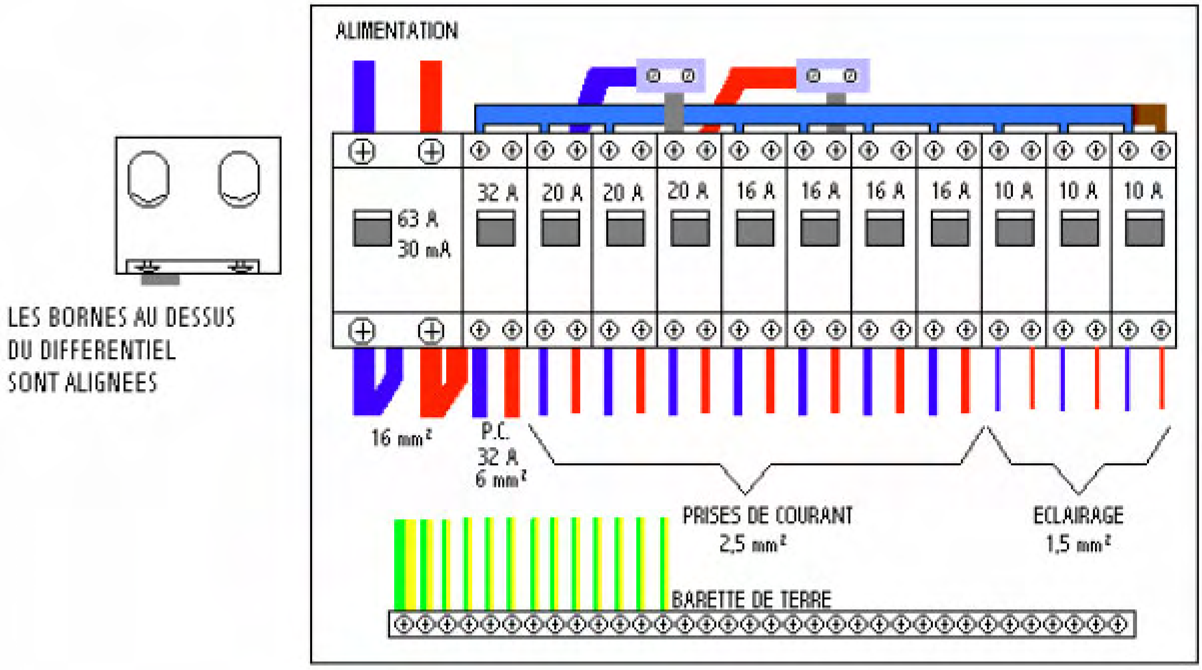


Figure 132: Constituent elements of a customer switchboard

A CUSTOMER SWITCHBOARD or *fuse (or breaker) board* is used for separating the house's different circuits.

It consists of a support (metal and/or plastic), on which protectors consisting of breakers or fuses are mounted.

It also has a strip to which all the house's earth wires are connected.

In the case of fuses or breakers, the cut-out/protection is now always bipolar. On old switchboards, with protection/cut-out on phase only, an earth strip <u>and</u> a neutral strip can be found.

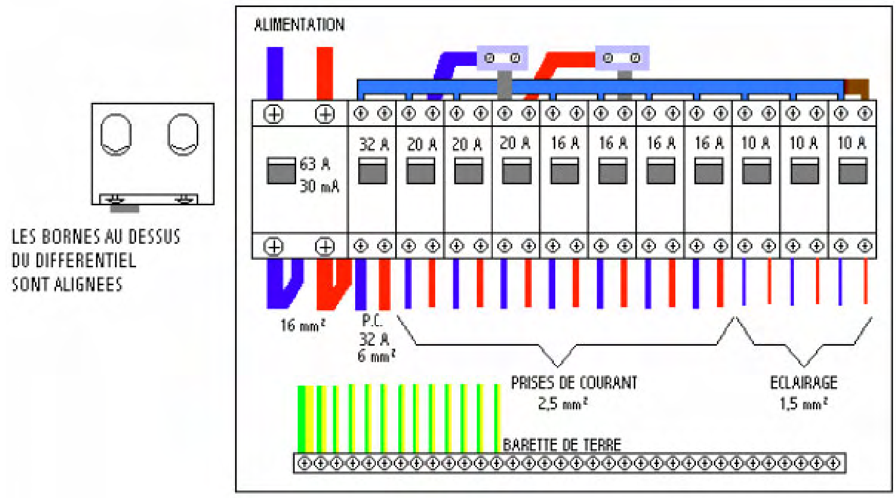


Figure 133: Bipolar distribution from switchboard

General protection is provided by a differential breaker

12.3.4. The different circuits

12.3.4.1. Specialised lines

These are lines supplying sockets where specific devices are plugged in. These circuits are continuous from the switchboard to the points of use, with ***no cut-outs on the way***

- 32 A circuit: for oven or electric cooker
- 20 A circuit: for the washing machine
- 20 A circuit: for the tumble dryer
- 20 A circuit: for the dishwasher
- 20 A circuit: for the water heater

12.3.4.2. Normal lines.

These lines may supply several points, and so may be cut. They are grouped in branch boxes.

- 16 A circuit: for normal current sockets
- 10 A circuit: for lighting circuits
- 2 A circuit: for ancillary circuits (buzzer, EDF control circuit protection on electric water heater, etc.).

12.3.5. Some rules to follow

In electrical installations, there are 2 colours to observe: ***blue*** which is only used for ***neutral***, and ***green / yellow*** which is reserved for the ***earth*** circuit.

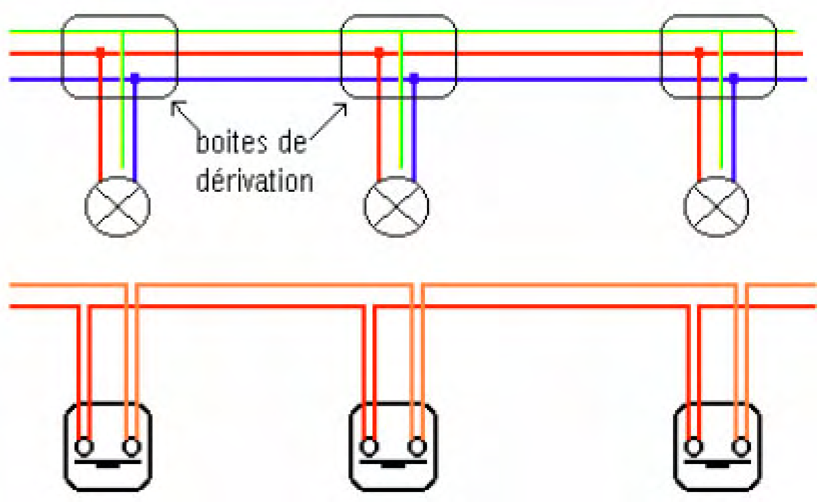
We can only put two wires at most in breaker terminals.

The cross-section of conductors relates to the surface area of the copper wire. There are wire cross-sections that correspond to precisely defined usage power levels.

- 1.5 mm² lighting circuit, buzzer and anything else not requiring a high power level.
- 2.5 mm² current socket circuit, normal socket, washing machine, tumble dryer, water-heating circuit.

- 6 mm² electric cooker circuit
- 10mm² supply up to 60 Amperes (12 KW in single-phase)
- 16mm² supply up to 90 Amperes (18 KW in single-phase)

12.3.6. Circuit wiring



All devices, whether pushbuttons or lights, are wired in parallel.

Figure 134: Circuit parallel wiring

It is possible to mount pushbuttons with indicators, but without exceeding the number indicated by the manufacturer of the remote control / timer.

Wiring of current sockets: In each circuit, there is a limit of 5 sockets, under application of the "PROMOTELEC" standard
Each socket is done individually.

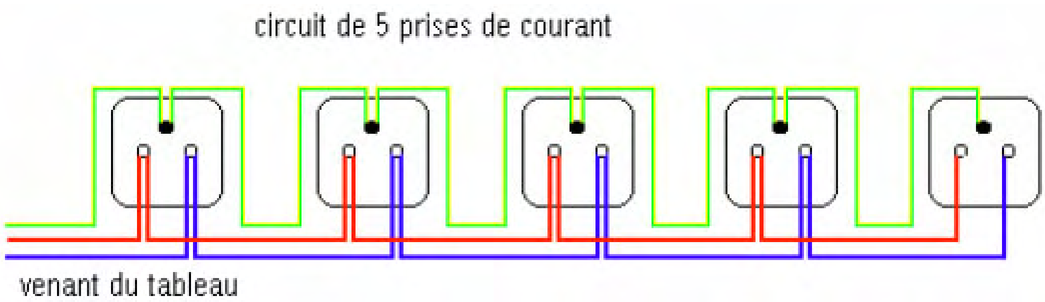


Figure 135: Parallel wiring of current sockets

And now we are just left with….

13. EXAMPLE OF DIAGRAM READING

Now let's go back to industrial diagrams, primarily focusing on schematic diagrams.

A site electrician, for each system and distribution cabinet, has a set of plans in A3 and/or A4 format with 'n' sheets representing the installation "sequential" in control (or command) diagram and power diagram form

If you are on a site, the most logical thing would be to do an application or an exercise on a 'concrete' example, on a real object. Get hold of the necessary sets of plans (instructors and pupils) and work on them, rather than on the example below

But this example explains ***how to read and interpret a schematic diagram***, and if you are a novice, you should go through the explanations and comments step by step

Example of control and command of a 3.6 MW synchronous motor on the Lacq site

Let's look at the sheets making up the schematic diagram "book"

This book contains 46 pages (sheets)

Before these 46 sheets, there is the ***cover sheet*** with the title block, information on the site, the design & engineering dept., the system concerned and revisions history (with dates).

Sheet 01: list of pages/sheets with description of contents of each page and the indices of the various revisions / modifications (date and details on cover sheet).

Note that the grid linking system uses numbered columns and lettered rows

	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39
A																				
B																				
C																				
D																				
E						⇑									-					
F					⇐	F-11					Area for text and diagram -									
G																				
H																				
I																				
J																				

A link can cover one or more columns (without a row) or one or more rows (without a column reference)

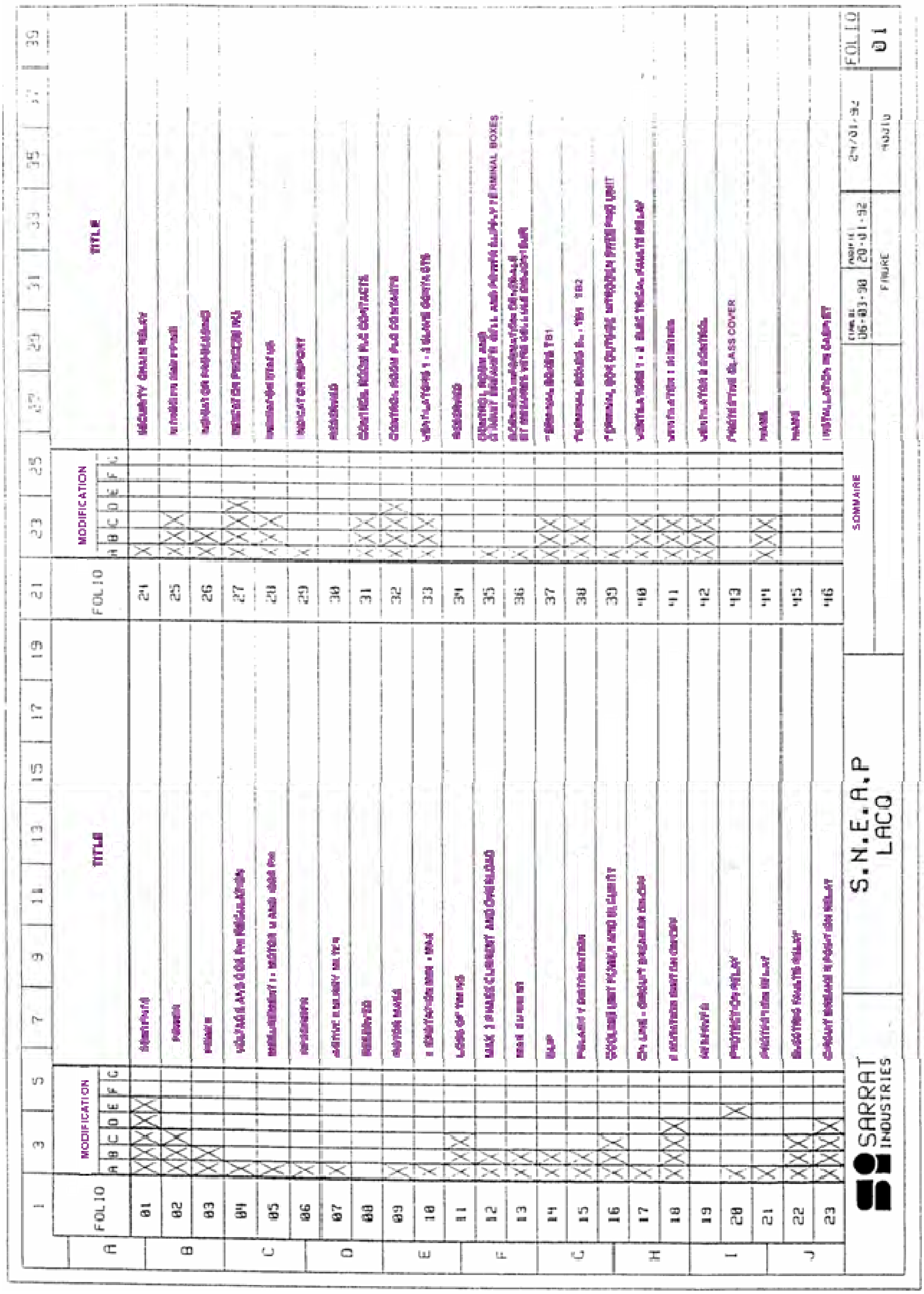


Figure 136: Synchronous motor control – Sheet 01

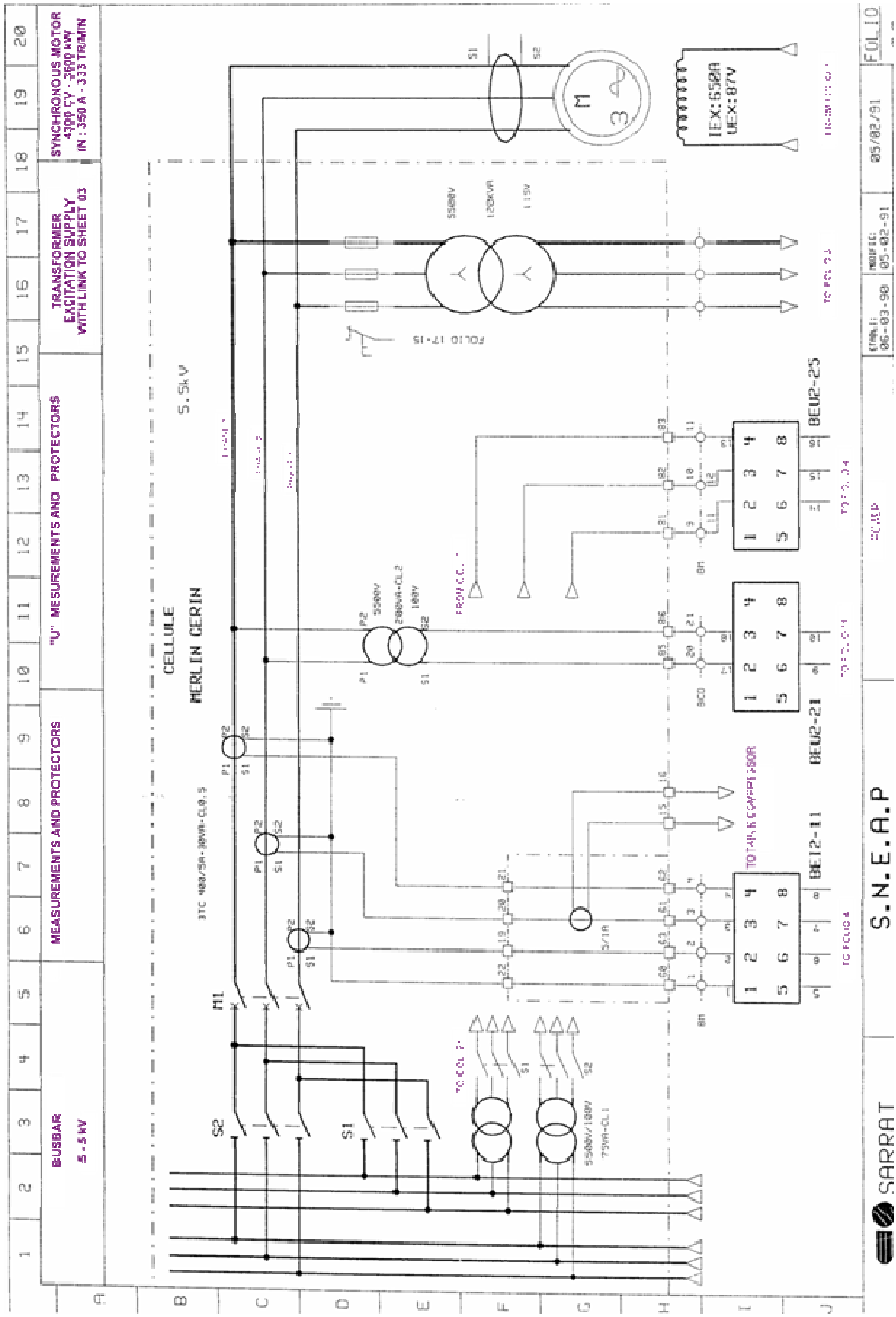


Figure 137: Synchronous motor control – Sheet 02

Sheet 02: power diagram

A draftsman can make mistakes! On this page, the horizontal references are noted from 0 to 20, while the interior text adopts odd numbering; 1, 3, 5, up to 39 (error recurring several times in the book). *You are required from the outset to be able to read plans, and also detect errors….*
For example in column 4 (which is actually 7) the output of the TPs indicates a link to "COL.21", i.e. on the same page. In column 21 (indicated 11), we find the original indication "FROM COL.7" (indicated 4)

Row A: names of equipment and circuits concerned found in the demarcated column
- 5.5 kV busbar: with 2 isolators, the 5.5 kV breaker and TPs
- Current 'I' measurements and protectors: with TCs, connector 'I' and links
- Voltage 'U' measurements and protectors: TPs, connectors and links
- Transformer: excitation supply with link to sheet 03
- Synchronous motor

Merlin-Gérin cell: demarcated by axis lines
All HV 5.5 kV cells covering the equipment mentioned above (except the motor). Layout plan of cells and equipment in another book, the HV book, not covered in this 46-sheet (LV) book.

HV terminal block: none! Generally we do not number the HV "wires and terminals" (except in complex HV distribution). As for the numbering of the HV cables, it will be in the HV book (wiring of HV cells)

LV terminal block: The LV wiring going out from the Merlin-Gérin cells is connected to terminal blocks, which in this case are denoted 'BM' and 'BCO'. The connection between the terminal blocks can be found later in the book, on sheets 35 to 39.

Equipment identification: all the LV elements are identified and listed in the listing on sheet 44. On this sheet 02, primarily regarding HV, the references and listings should be looked up in the HV book (not covered)

In the LV equipment, for example on this sheet 02, I don't know what 'BE12-11' is; the listing specifies that it is a *"GEC Alsthom Intensity Secura Unit"*, i.e. a connector for external measurements and calibrations.

Links to other sheets:
In row 'J', identification of pages where the 'wires' can be found

Wiring identification: each LV 'wire' has its own number, which can be found on the various sheets concerned, and with the appropriate links.

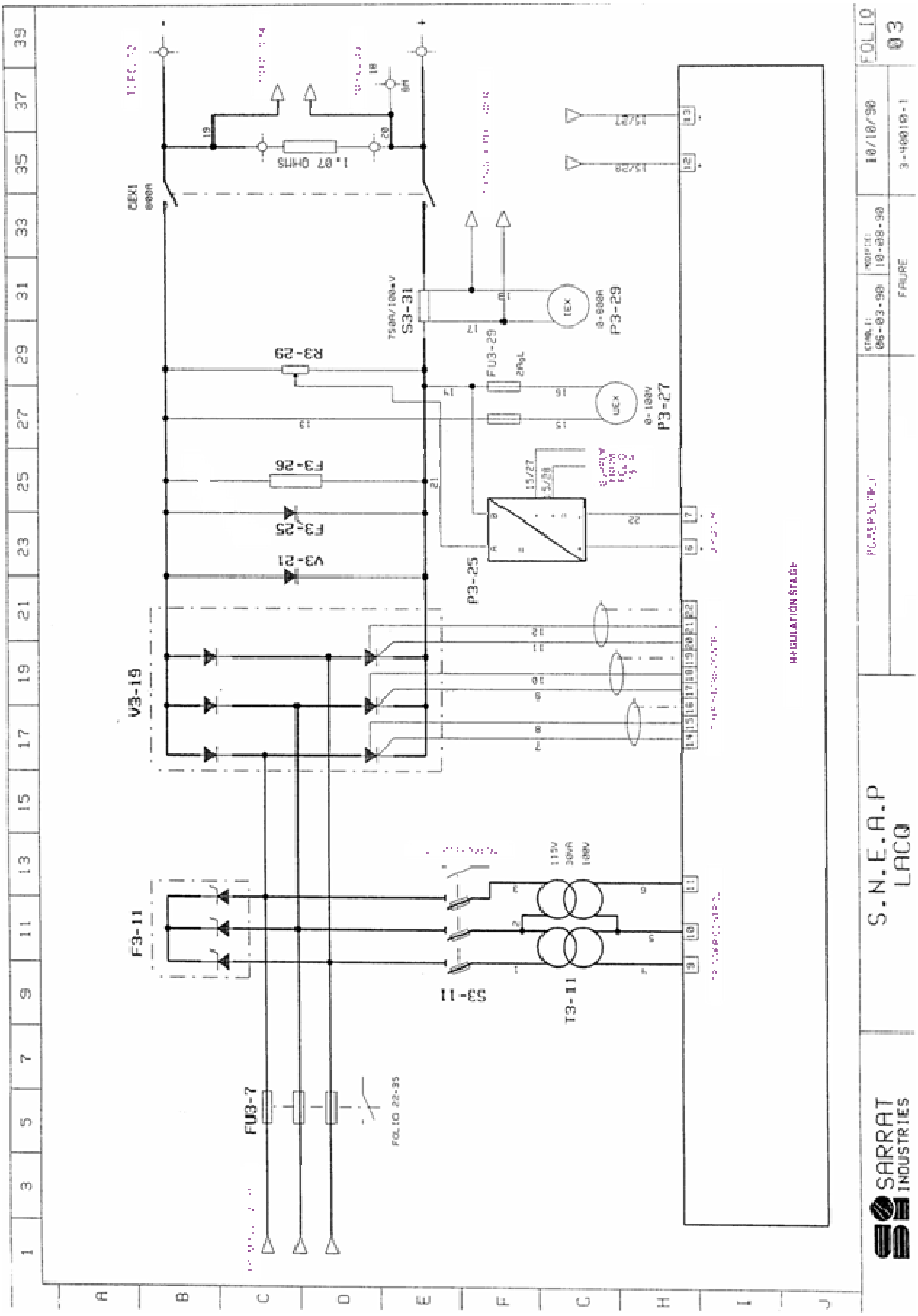


Figure 138: Synchronous motor control – Sheet 03

Sheet 03: Power supply (excitation and regulation stage)

Power supply from sheet 2 column 31 (numbered 16), as indicated at point C1

The protection fuse FU3-7 has a '*fuse fault'* contact which can be found on sheet 22 column 35 as indicated in D5
Ditto for S3-11, which has an incorporated '*fuse fault'* contact in the diagram on sheet 22 column 37

Power supply return in column 39 to sheet 02. Also link to sheets 14 and 09 for protectors and control

Sheet 04: Voltage and cos phi regulation

Appearance of **distribution bars**

Rows B and C, from box BE12-11 on sheet 02 column 11 (6), the secondary currents (from TCs) with references 2/5, 2/6, 2/7, 2/8 are distributed and carried over to the following sheets. These bars are renamed 13, 12, 11 and N

Rows H and I, the secondary voltages (from TPs) are distributed. They originate from box BEU2-25 column 25 (13) with tags 2/14, 2/15, 2/16 and are renamed u1, u2, u3

Relay contacts:
Appearance of first relay contacts: KA23-3 and KA18-17. The coils (and their integration in a circuit) can be found respectively on sheet 23 column 3, and sheet 18 column 17.
On sheets 23 and 18, on the coils of these relays, the link to sheet 04 for the contacts concerned can be found.

Sheet 05: I, U and motor cos phi measurements
Not copied in this document
Between the "current bars" and "voltage bars" the following are represented: 3 ammeters, 1 voltmeter, 1 phi-meter (switchboard panel indicators)

Sheet 06/ Sheet 07: Active energy recorder / Meter
Not copied in this document
Connection of a recorder and meter (switchboard) with the U and I bars

Sheet 08: Spare –'empty' sheet

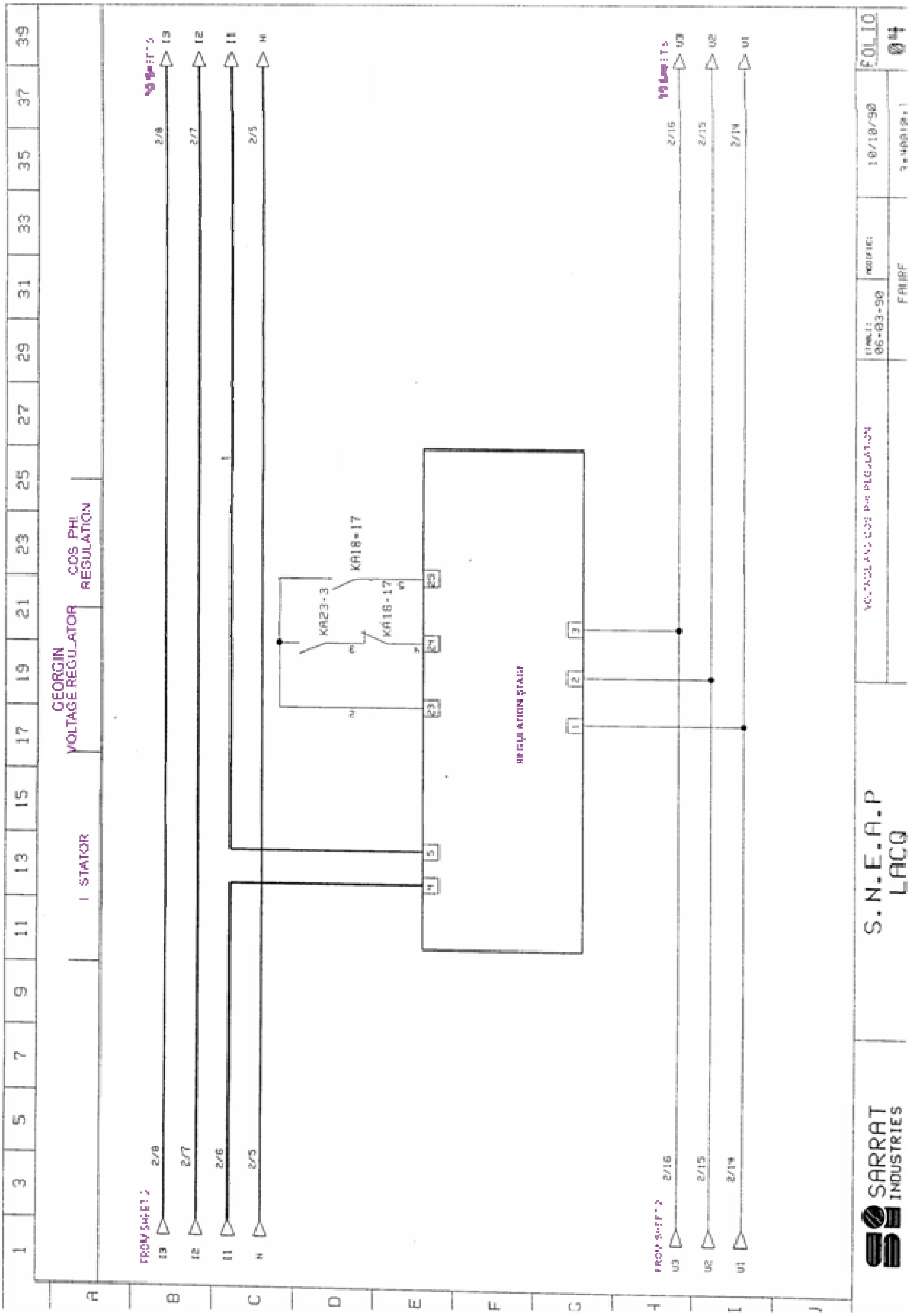


Figure 139: Synchronous motor control – Sheet 04

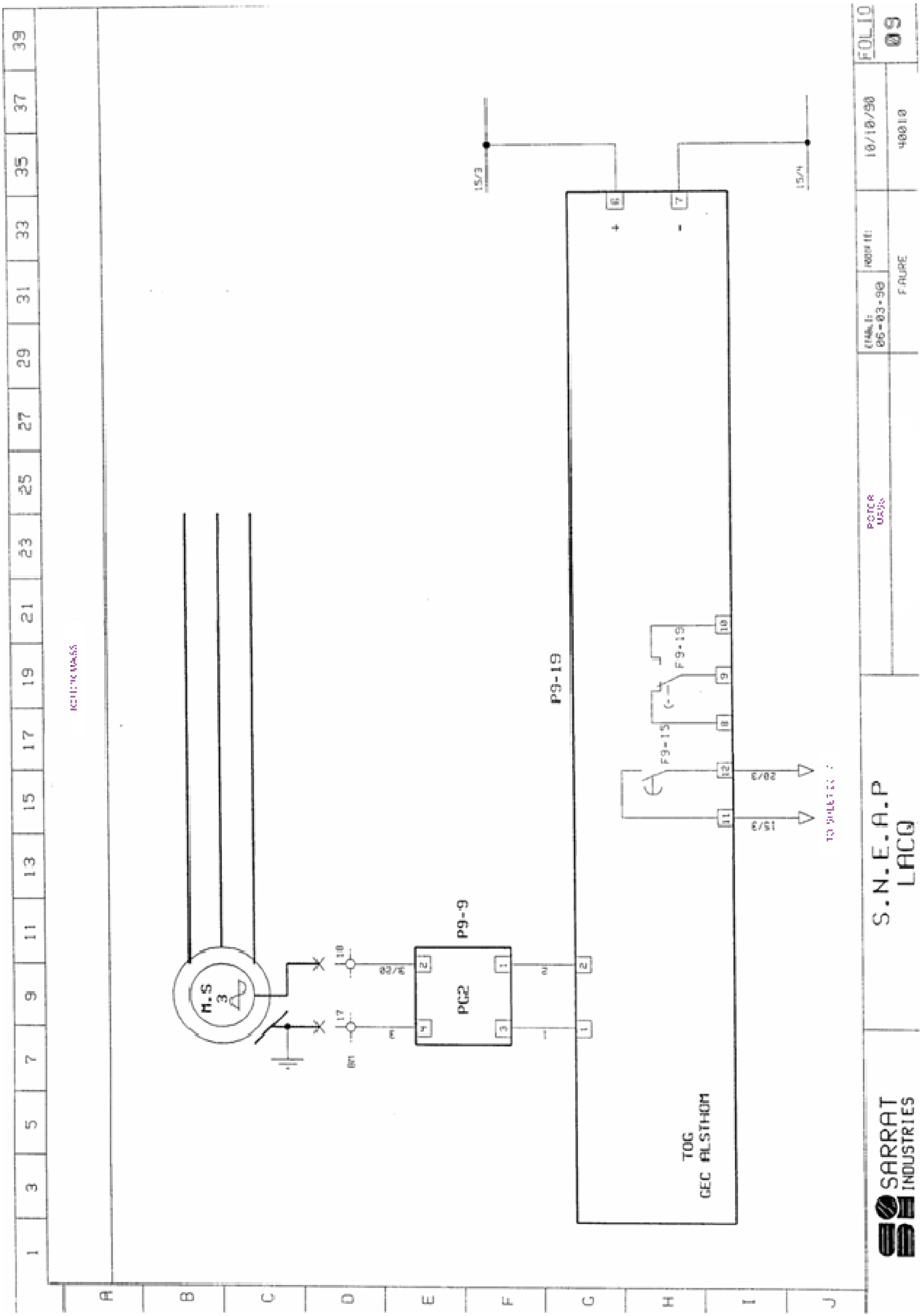


Figure 140: Synchronous motor control – Sheet 09

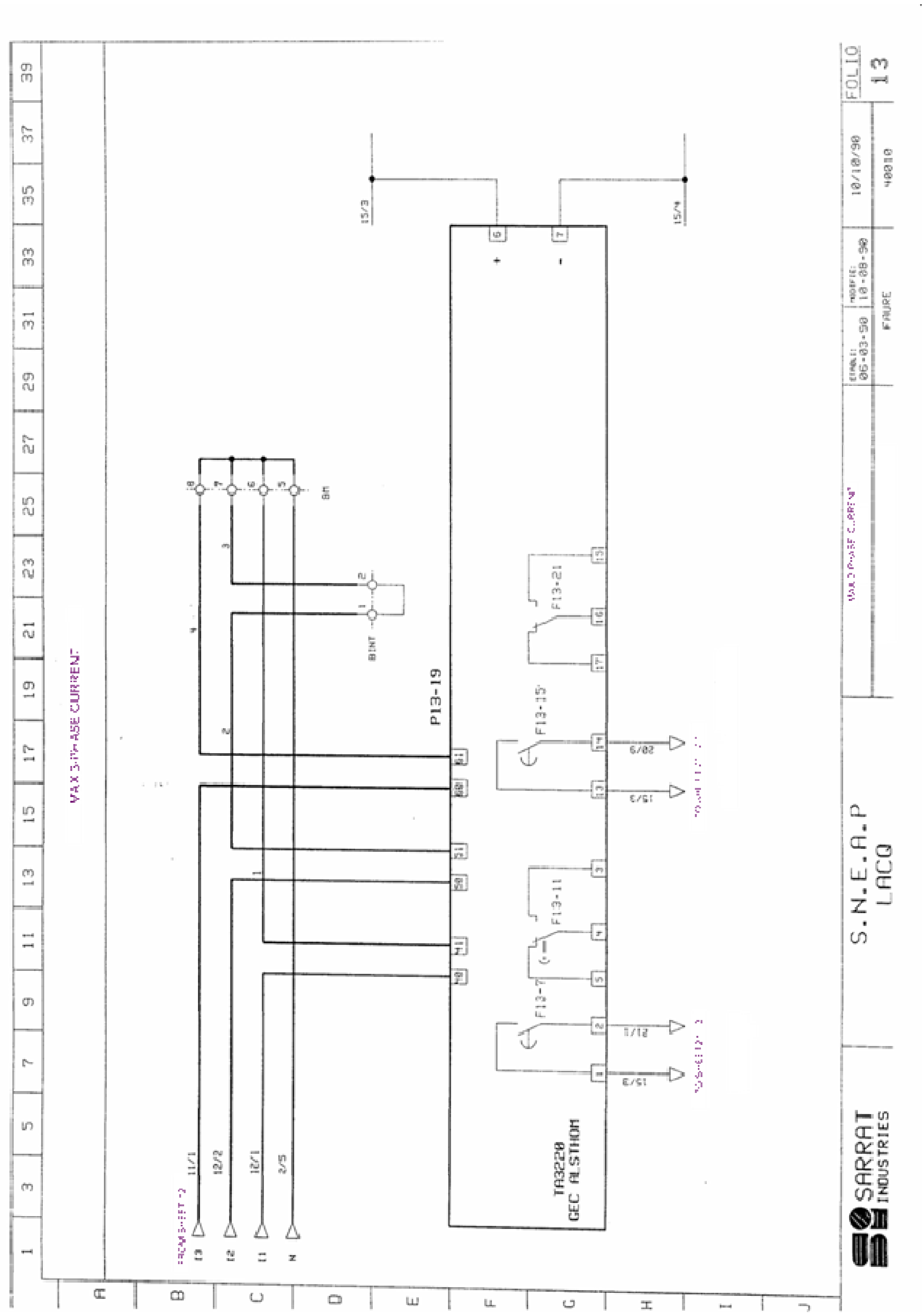


Figure 141: Synchronous motor control – Sheet 13

Sheet 09: Motor rotor earth
GEC Alsthom's TOG protective relay, detecting any earthing fault on the rotor with 125V DC supply (from sheet 15 column 3), and generating an alarm via time-lag NO contact to sheet 20 column 7

Sheet 10: Excitation Min – Max
GEC Alsthom's TUG 1111 protective relay, detecting the excitation min level (no excitation, open circuit), and excitation max level (short circuit on rotor or overload, short circuit on stator), with same supply as the previous relay. Delivers 2 time-lag NO contacts (min and max) to sheet 20, col. 13 and 17
Not copied in this document

Sheet 11: Loss of synch
GEC Alsthom's T2G protective relay, with 115V DC supply as above, receiving the voltage image from sheet 3. Time-lag NO contact to sheet 20 col. 23
Not copied in this document

Sheet 12: Thermal overload
GEC Alsthom's TA3220 protective relay, detecting phase current upper threshold (I>), with supply as above. Time-lag NO contact to sheet 20 col. 33
Not copied in this document

Sheet 13: Three-phase current max (Thermal overload >>)
GEC Alsthom's TAT430 protective relay, with supply as above, sending a time-lag NO contact to alarm (sheet 21 col.3) and a time-lag NO contact to sheet 20 col.23 for fault relaying circuit.

Sheet 14: Slip
GEC Alsthom's VTM protective relay, with supply as above, sending an NO contact to sheet 18 col. 3 in the excitation contactor control circuit
Not copied in this document

Sheet 15: Distribution of polarities
Supply / "dispatching" at the necessary voltages for the system's various receivers
Column 3: 125V DC to protective relays sheets 09 to 13
Column 7: 24V DC to sheet 3, excitation regulation stage
Column 11: 24V DC to sheet 26, signalling panel (polarities 29 and 30)
Column 17: 380V three-phase to cooling unit (sheet 16)
Column 21: to sheet 40, polarities 37 and 38 of fan control circuit
Column 31: to sheet 6, recorder 220V AC supply
Column 35: to sheet 14, slip protection relay 220V AC supply

Sheet 16: Cooling unit supply and safety
"Box P16-9"?... If I can't see what it is, I go into the listing (sheets 45 -45) which specifies: '*cooling block*'. So it is a self-managing system, with three-phase 380V AC supply (sheet 15 col. 17), which has an outgoing fault NC contact (P16-9 *for page 16 col.9)* in the control circuit, see on same sheet col. 23

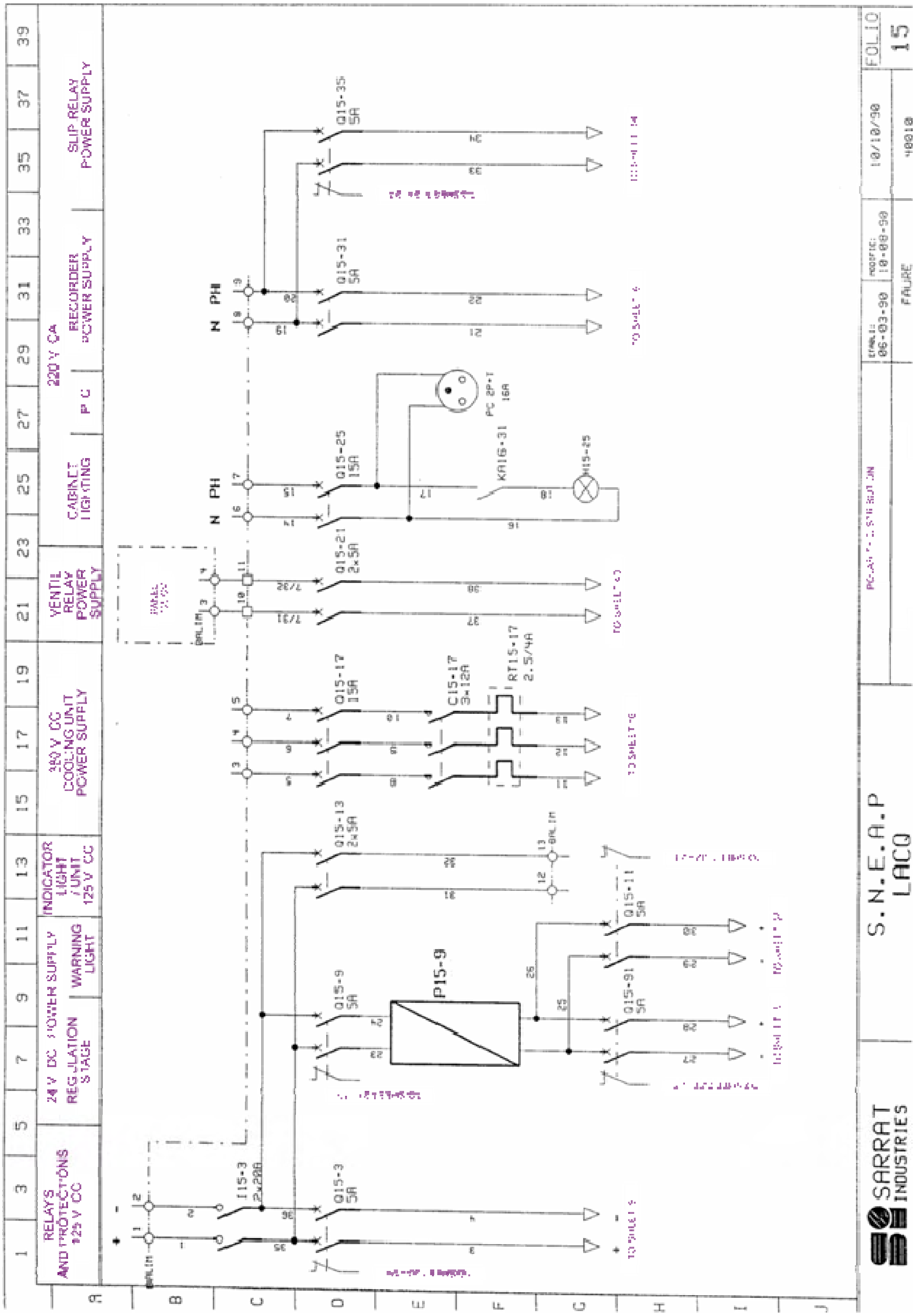


Figure 142: Synchronous motor control – Sheet 15

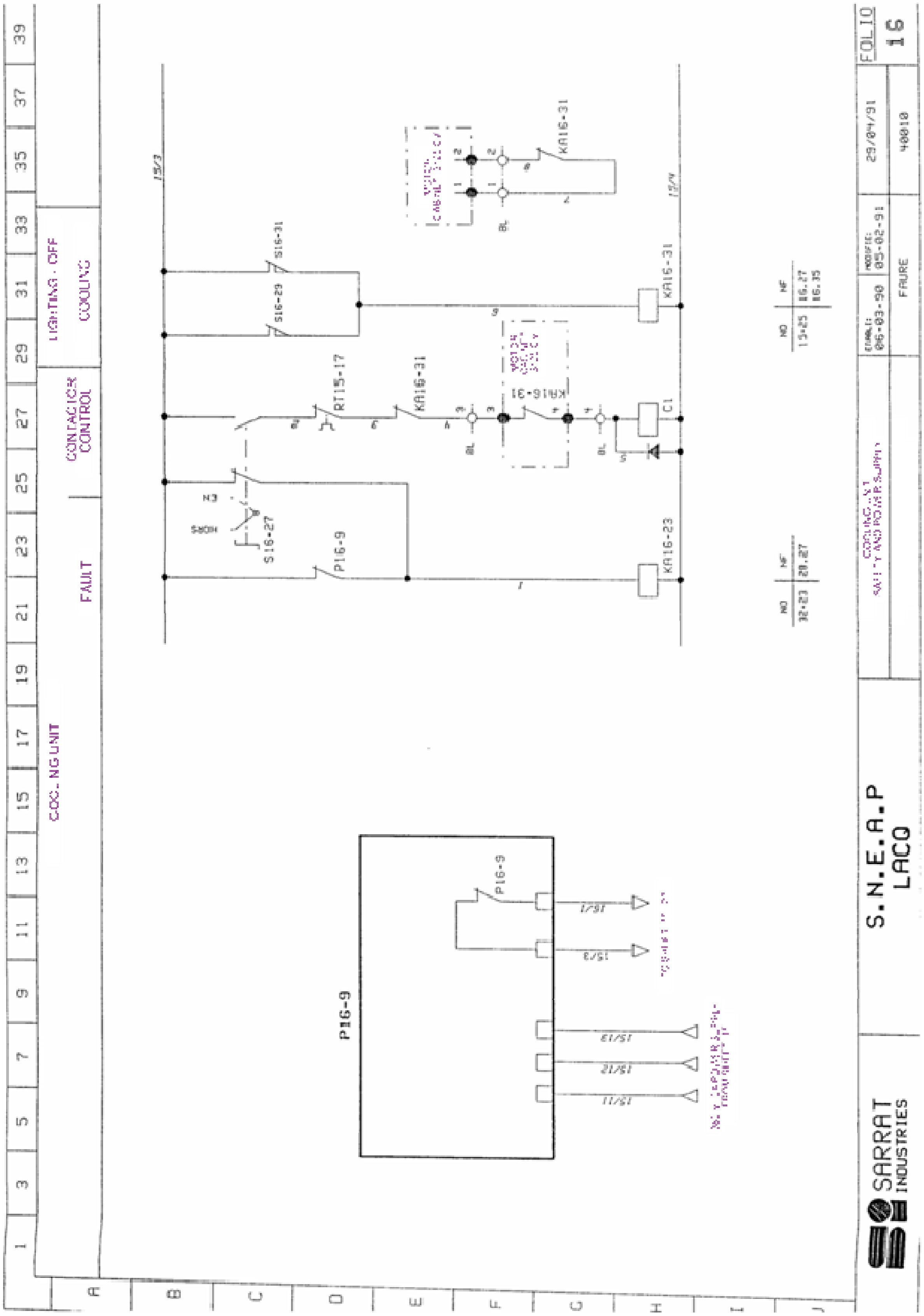


Figure 143: Synchronous motor control – Sheet 16

Sheet 16 (continued):
Schematic diagram: 1st relaying diagram with
- Distribution bars (15/3 and 15/4) supplied from the breaker Q15-3 (sheet 15 col. 3)
- Relays:

KA16-23, fault relay (in col. 23) with an NO contact which can be found in 32-23 (sheet 32 col.23) and an NC contact in 28-27.
KA16-31, lighting relays (actuated by gate – travel limit contacts, S16-29/31), with an NO contact that can be found in sheet 15 col. 25 (lamp circuit) and 2 NC contacts on this sheet (cooling unit starting lock)
- The coil on contactor C1, with the command/control contacts in series.

Sheet 17: Line breaker engagement/trip (for 4300 HP motor)
With (supply) polarities received in the Merlin – Gérin (HV) cabinet
We can find in series: all the stop contacts, emergency shutdowns, fuse blowouts and make contact KA24-11 (relays on sheet 24 col. 11)

Sheet 18: Excitation contactor engagement/trip
Schematic between polarities 15/3 and 15/4

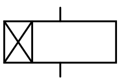
The "green light" is given from the Merlin – Gérin cabinet (time-lag contact M1) and thereafter we need only follow the contact opening / closing and relay engagement sequences, referring to the contact / relay numbers leading to the sheet and column concerned …..

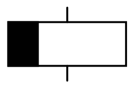
Note:
Wiring numbers: each 'wire' has its identification which can be found 'ringed' in the cabinet, with the sheet number

Wiring terminals: interconnections between cabinets and equipment 'run out' to terminals. In this case, with Merlin Gérin HV cabinets/cells on 'BCD' terminal block, terminals 7/8 and 4/5 (connected to terminals 48/49 and 44/45 of MG cabinet terminal block)

Time-lag contacts / relays:
Relay CEX1 actuates a time-lag NC operating contact (TT 18-3)

The 3 relays KA 18-13/21/25 are time-lag relays "ASA Syrelec, BLRM-U 127V DC", (this is confirmed by the listing on page 44). Be aware of the representation (yes, there is an error in the diagram). See the "***Symbols and standards***" course which contains exercises with time-lag contacts / relays

 TT Operating time-lag

TR Rest time-lag 

In addition, the contacts associated in this case with relays are represented as time-lag contacts (which is not actually untrue…)

As there are always reading (interpretation) problems with time-lag contacts (even for experienced electricians….), here is a recap of the symbols

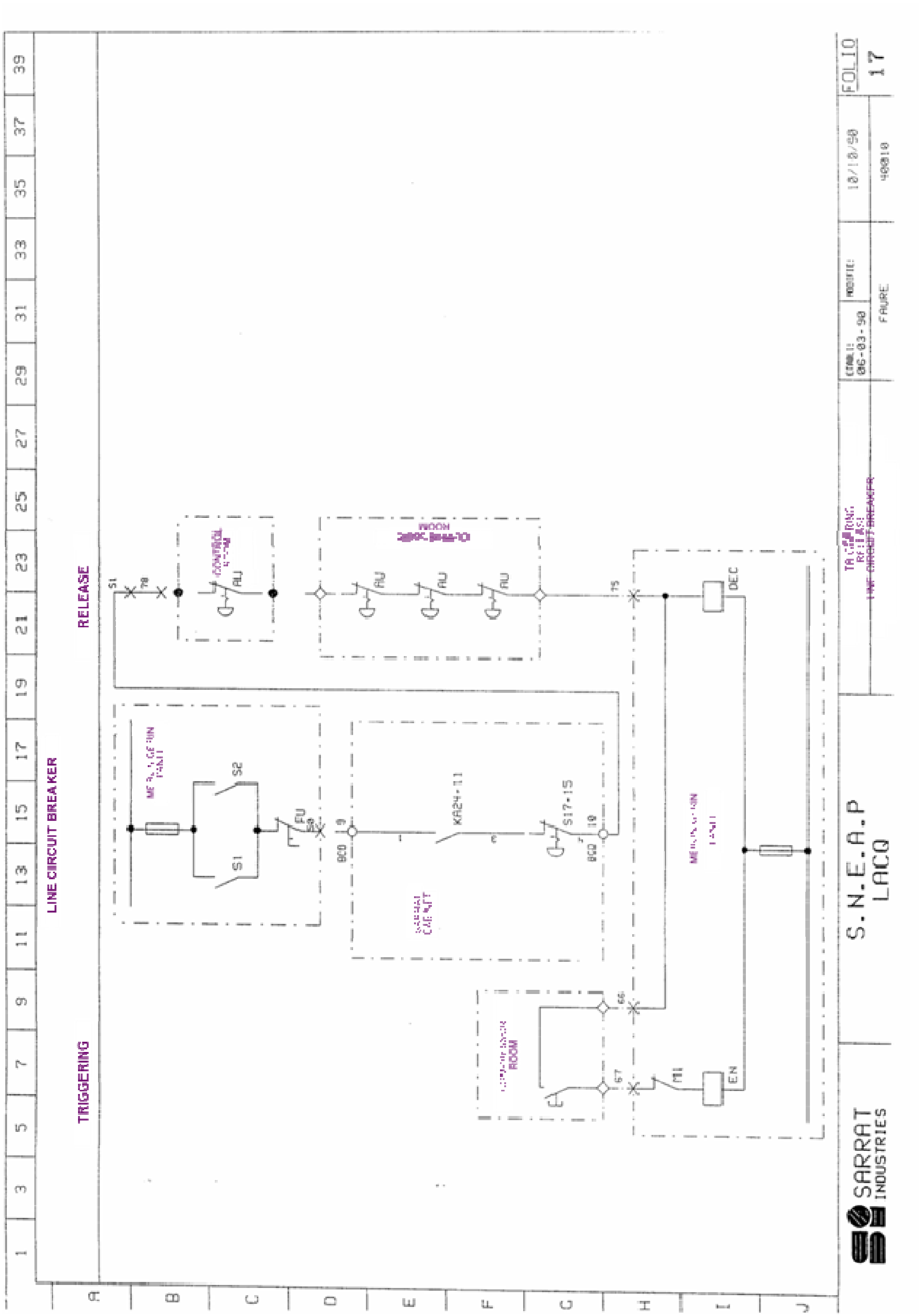


Figure 144: Synchronous motor control – Sheet 17

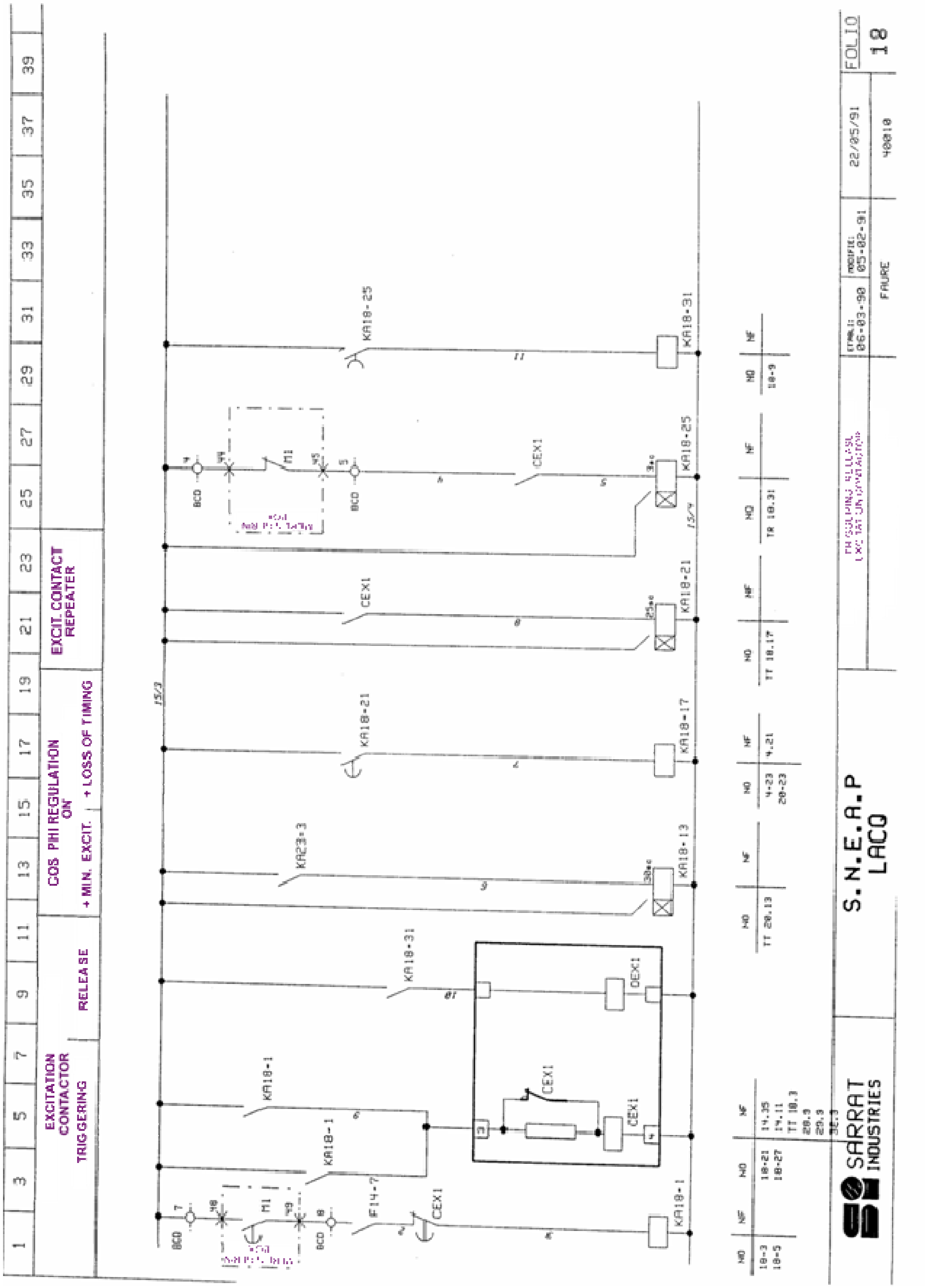
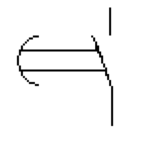
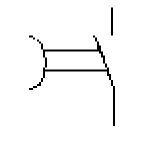
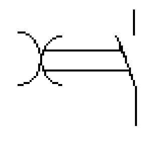
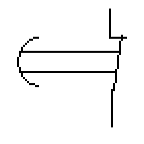
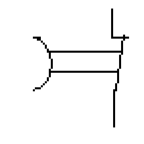
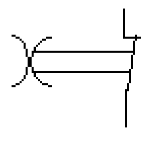


Figure 145: Synchronous motor control – Sheet 18

Sheet 18 (continued)

Recap of representation standards for time-lag contacts (***see course on symbols and standards***): *the direction of the 'umbrella' determines the time-lag action.*

	TT operating contact delayed on closing (attraction) = NO 'on' time-lag		TR operating contact delayed on opening (dropping) = NO 'off' time-lag		TTR operating contact delayed on closing and opening = NO 'on & off' time-lag
	TT rest contact delayed on opening (attraction) = NC 'on' time-lag		TR rest contact delayed on closing (dropping) = NC 'off' time-lag		TTR rest contact delayed on closing and opening = NC 'on & off' time-lag

Identification of circuits:
Row 'A', note the explication specifying the role / function of relays and contacts in the column concerned.

Sheet 19: Spare – empty sheet

Sheet 20/21: Protector relaying
Resumption of contacts initiated by fault relays (sheets 9 to 13), with relaying and link for each alarm
From an NO contact same sheet for self-powering
From an NO contact to sheet 26 or 27 – indicator panel
From an NC contact to sheet 24 – shutdown chain (all contacts in series)
From an NC contact to sheet 31 or 32 – automatic servo-controller input contact.
See fault acquisition bar (RaZ: Reset) from pushbutton S20-1

Page 21 not represented, just 1 relay device (KA21-3) for fault relay page 13, 'Max current level'.

Sheet 22: Electrical fault relaying
Between supply bars 15-3 and 15-4 + Reset bar 20-1
Follow the circuit logics, the numbering of the relays and contacts and the links to other sheets

Sheet 23: Breaker position relaying
Supply between bars 125V DC (15/3 and 15/4) and 24V DC supply bars (25/27 and 25/28).
24V DC supply from supply block P15-3 on page 15 col.7, wires 27 and 28. Be aware of the indications for the columns (discrepancy between indication 24 and 125V DC)

Sheet 24: Safety chain relaying
Break contacts in series on relay KA24-11, authorising engagement of the main breaker, sheet 17 col.15

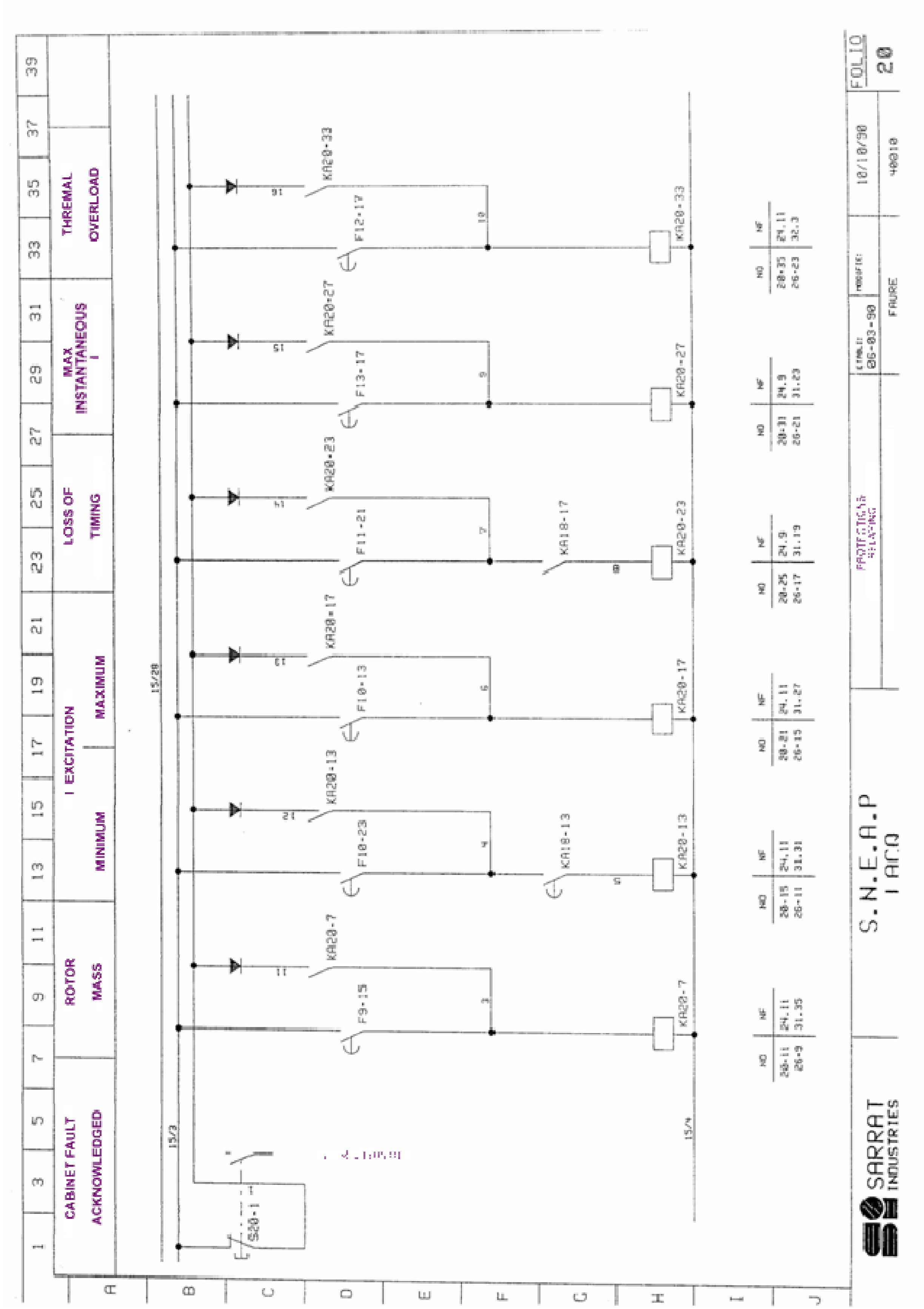


Figure 146: Synchronous motor control – Sheet 20

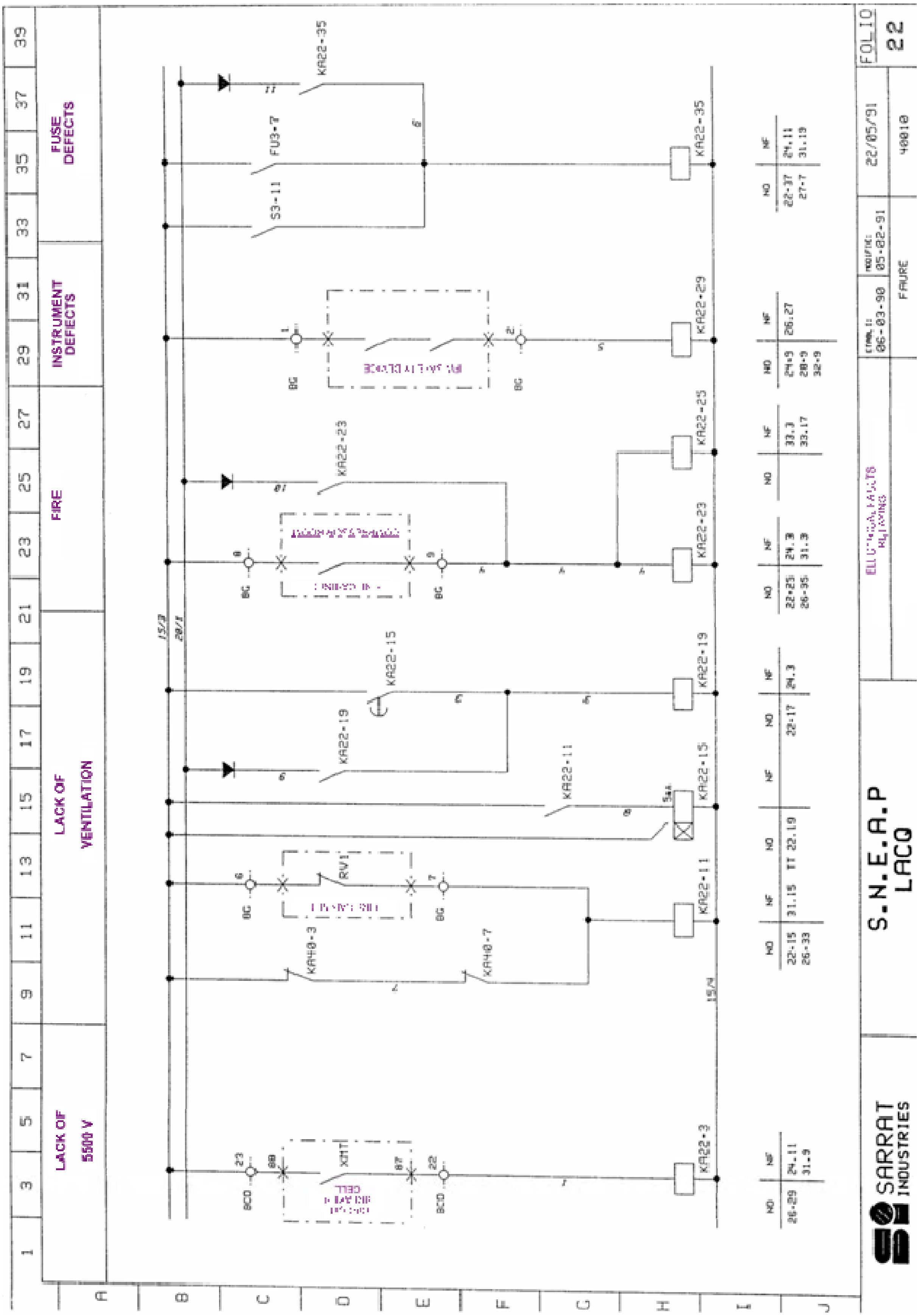


Figure 147: Synchronous motor control – Sheet 22

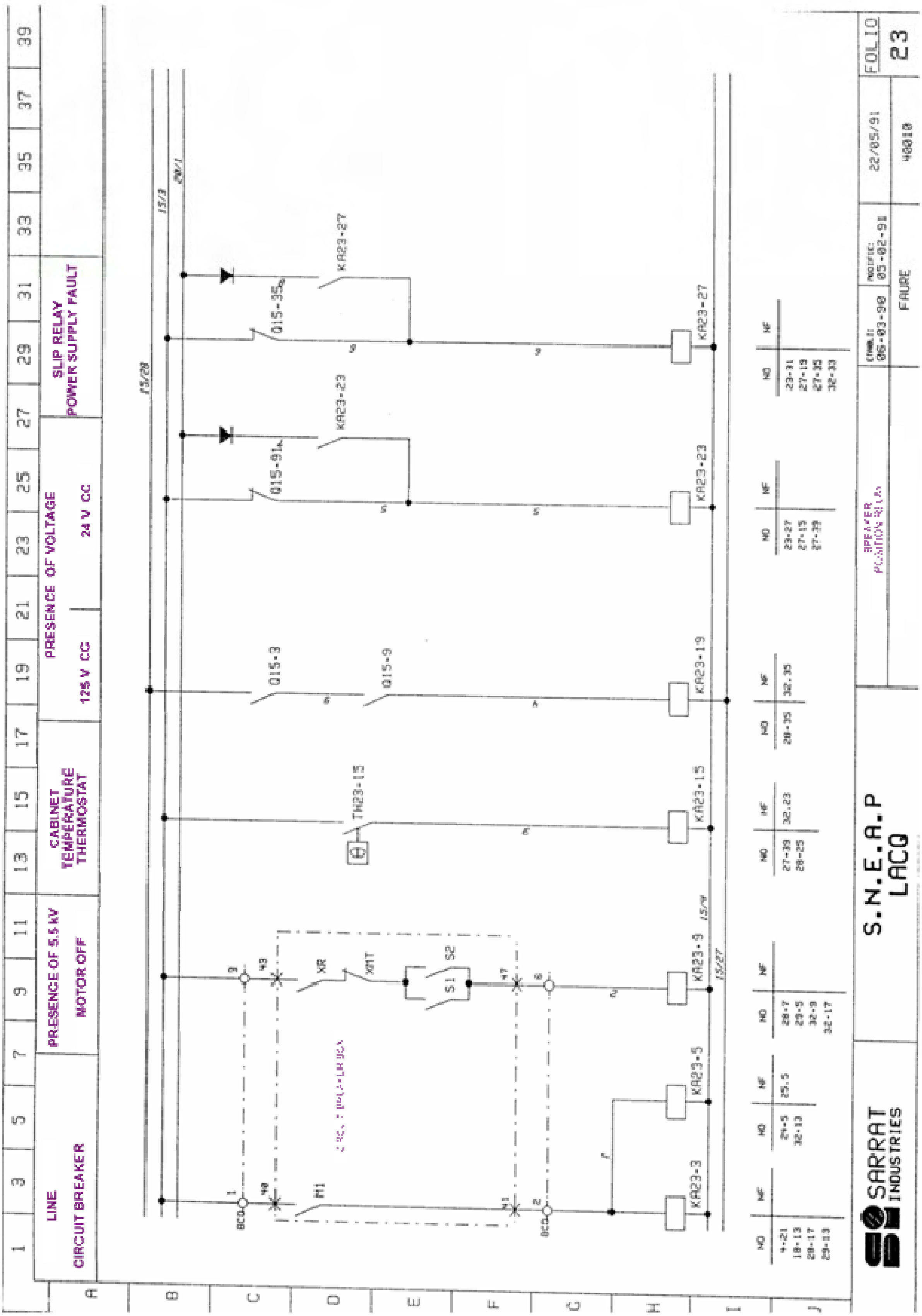


Figure 148: Synchronous motor control – Sheet 23

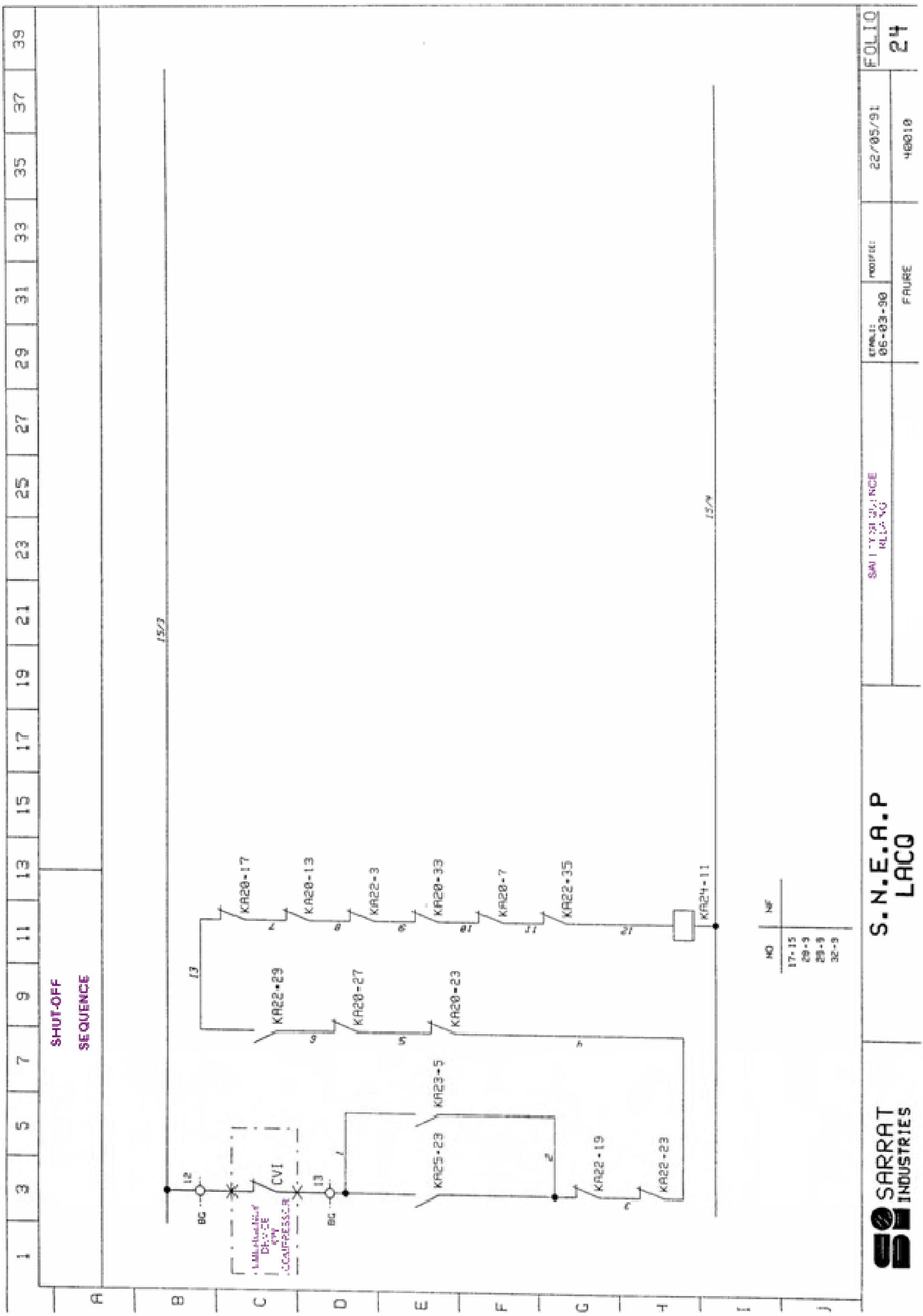


Figure 149: Synchronous motor control – Sheet 24

Sheet 25: Nitrogen flushing
Sequence to follow on diagram for engagement/trip of the 2 flush solenoid valves, with lock in the breaker engagement circuit via KA25-23, with an NO contact on sheet 24 col. 3
Parallel control via automatic controller col. 33

Sheet 26 and 27: Signalling processing
On Entrelec signalling block (listing on page 45)
Supply between bars 15/29 and 15/30 (24V DC block on page 15 col.11
Indicator lamps supplied via fault relay contacts on sheets 20/22/23

Sheet 28: Status Signalling (of operating sequences and conditions)
Supply to indicator lamps on switchboard panel

Sheet 29: Signalling transfer
"On", "off" and "start enabled" indicator lamps

Sheet 30: Spare sheet

Sheet 31/32: Transfer of automatic controller signalling to control room
Connections of sequence, signalling and fault contacts on automatic controller
Sheet 31 copied in this document, sheet 32 (identical) not copied

Sheet 33: Fan servo-control

Sheet 34: Spare sheet

Sheet 35: Relaying cabinet supply terminal block and breaker cell terminal block to control room
Representation of terminal blocks with
Terminal block identification: BALIM and BCD
Numbered terminals
Indication of wire number (sheet and number)
Explanation of "wire" function (destination / origin)
Cables and identifications: multi conductor 19x1.5 mm² on BCD

Sheet 36: General information and measurement terminal block to breaker cell
Not copied

Sheet 37: Terminal block BR1 – Cabinet / control room connection
Not copied

Sheet 38: Terminal block Control cabinet and fan cabinet (BL – BT1 – BT2) connections
Not copied

Sheet 39: Terminal block to nitrogen flushing box
Not copied

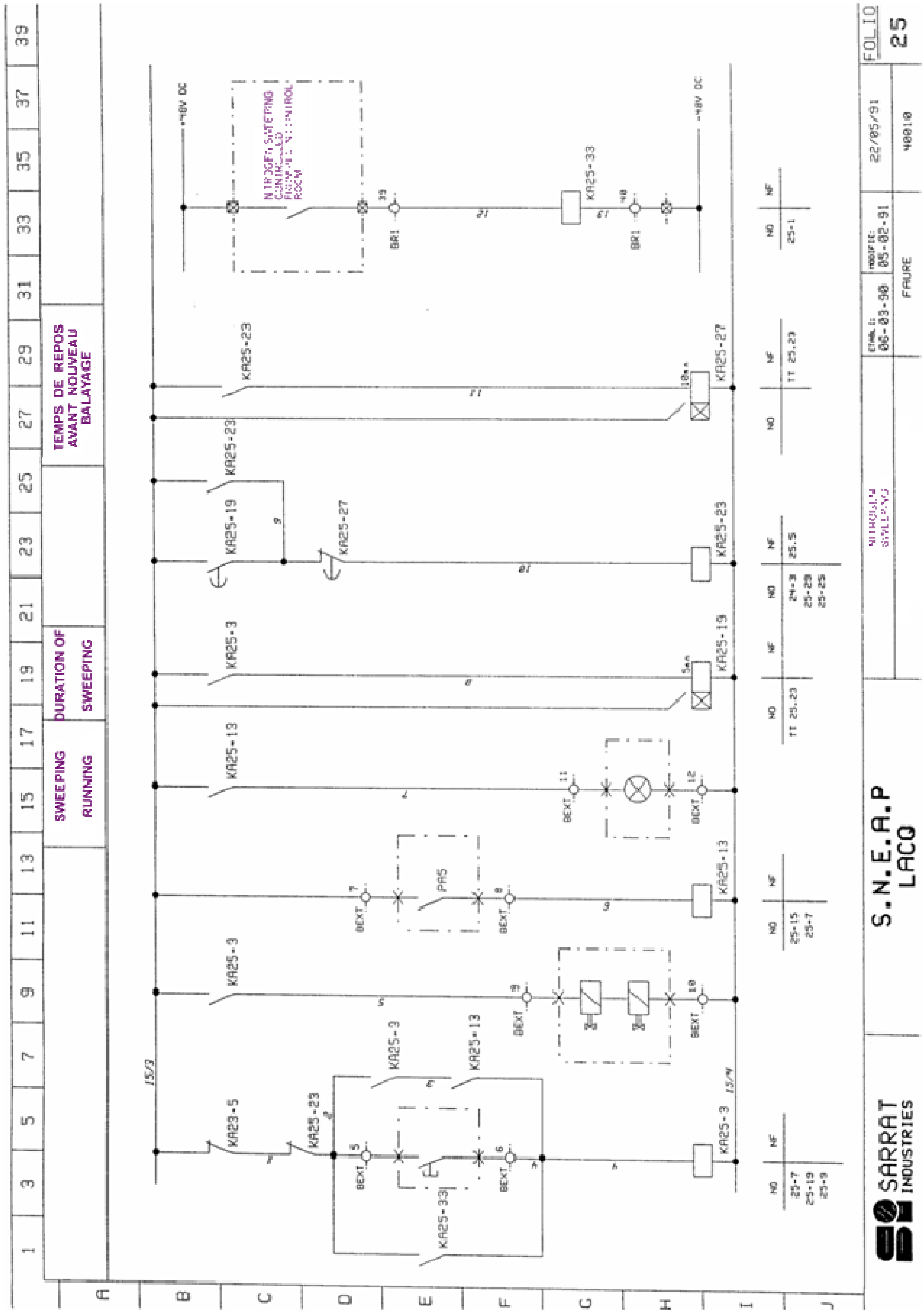


Figure 150: Synchronous motor control – Sheet 25

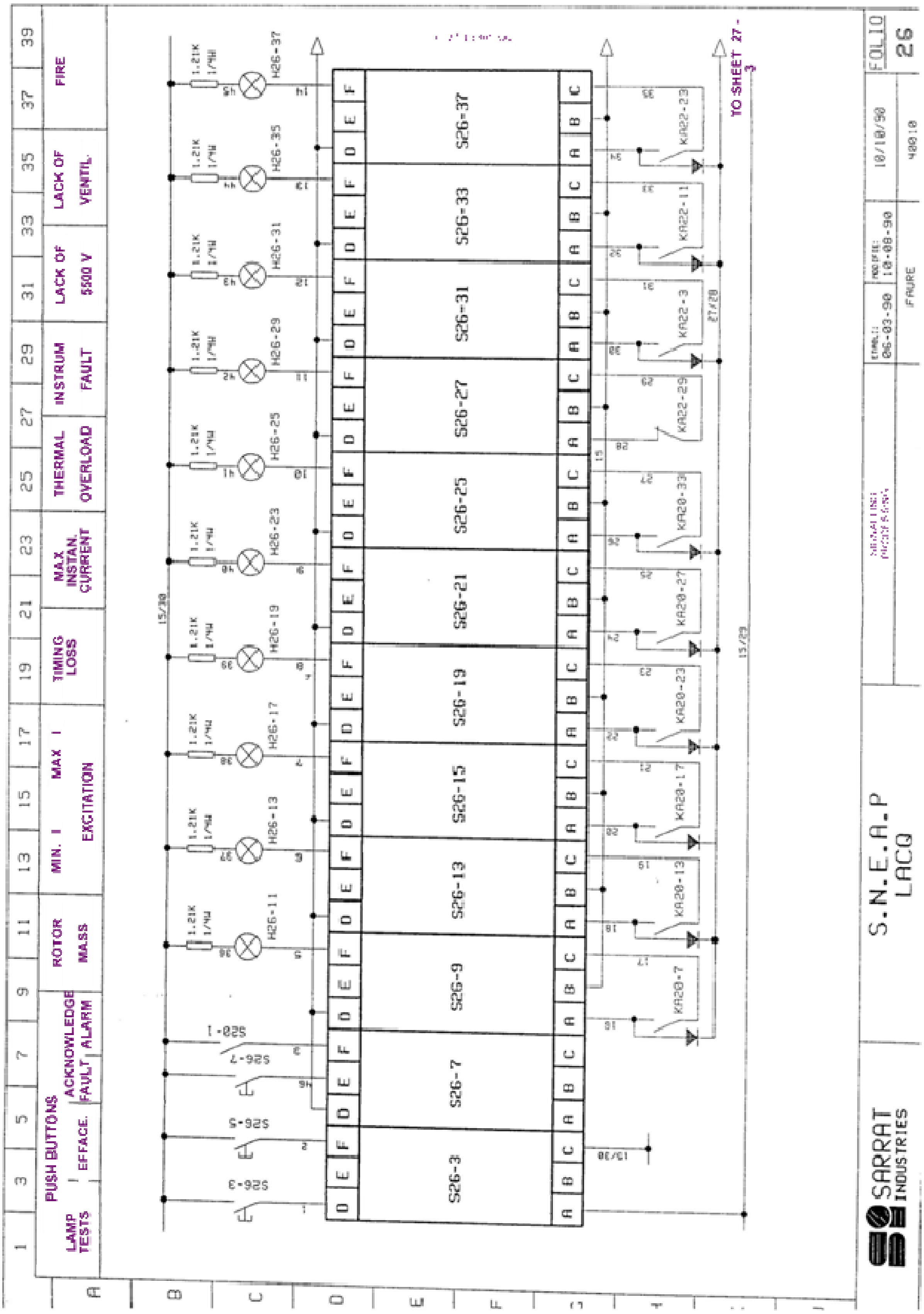


Figure 151: Synchronous motor control – Sheet 26

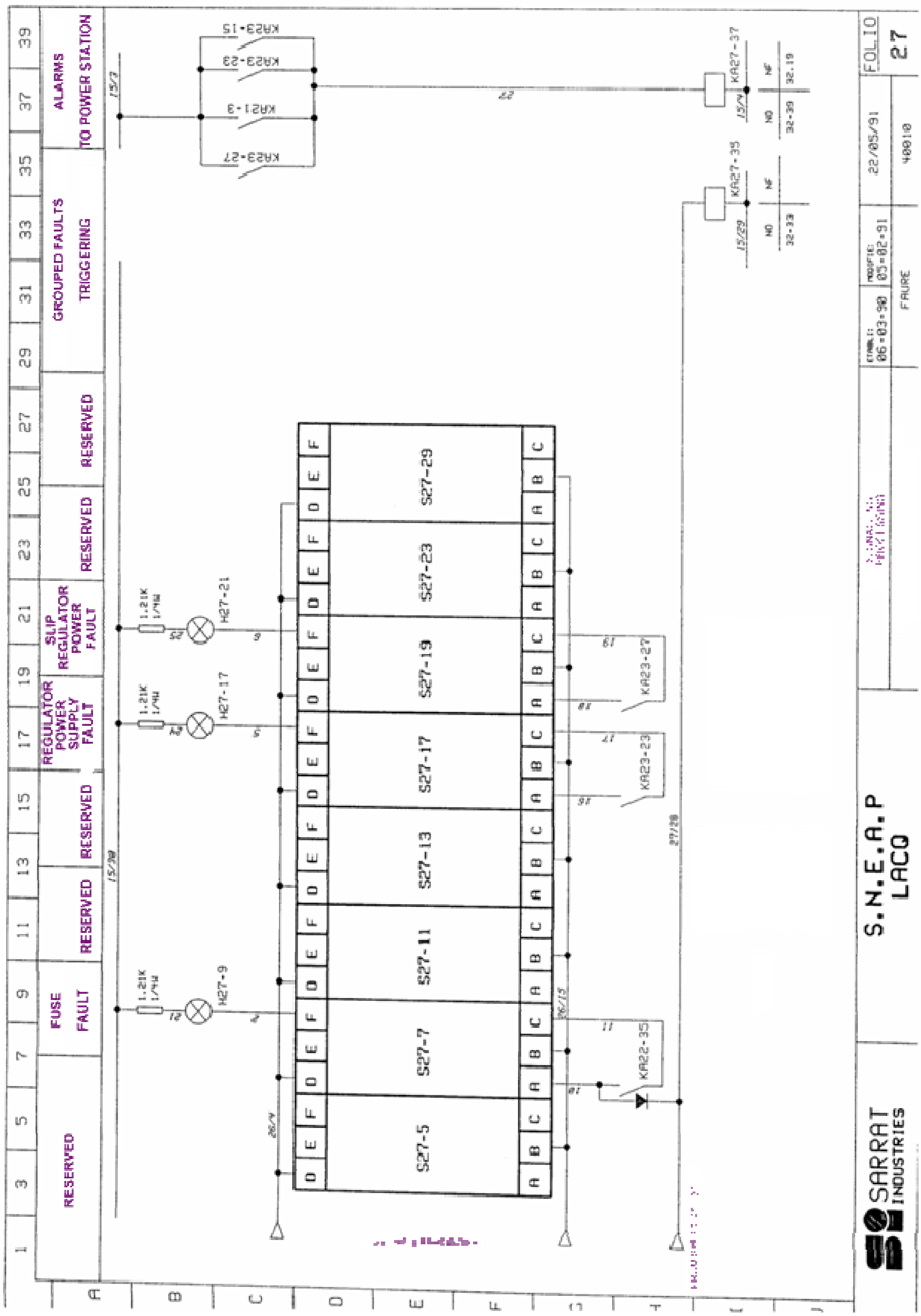


Figure 152: Synchronous motor control – Sheet 27

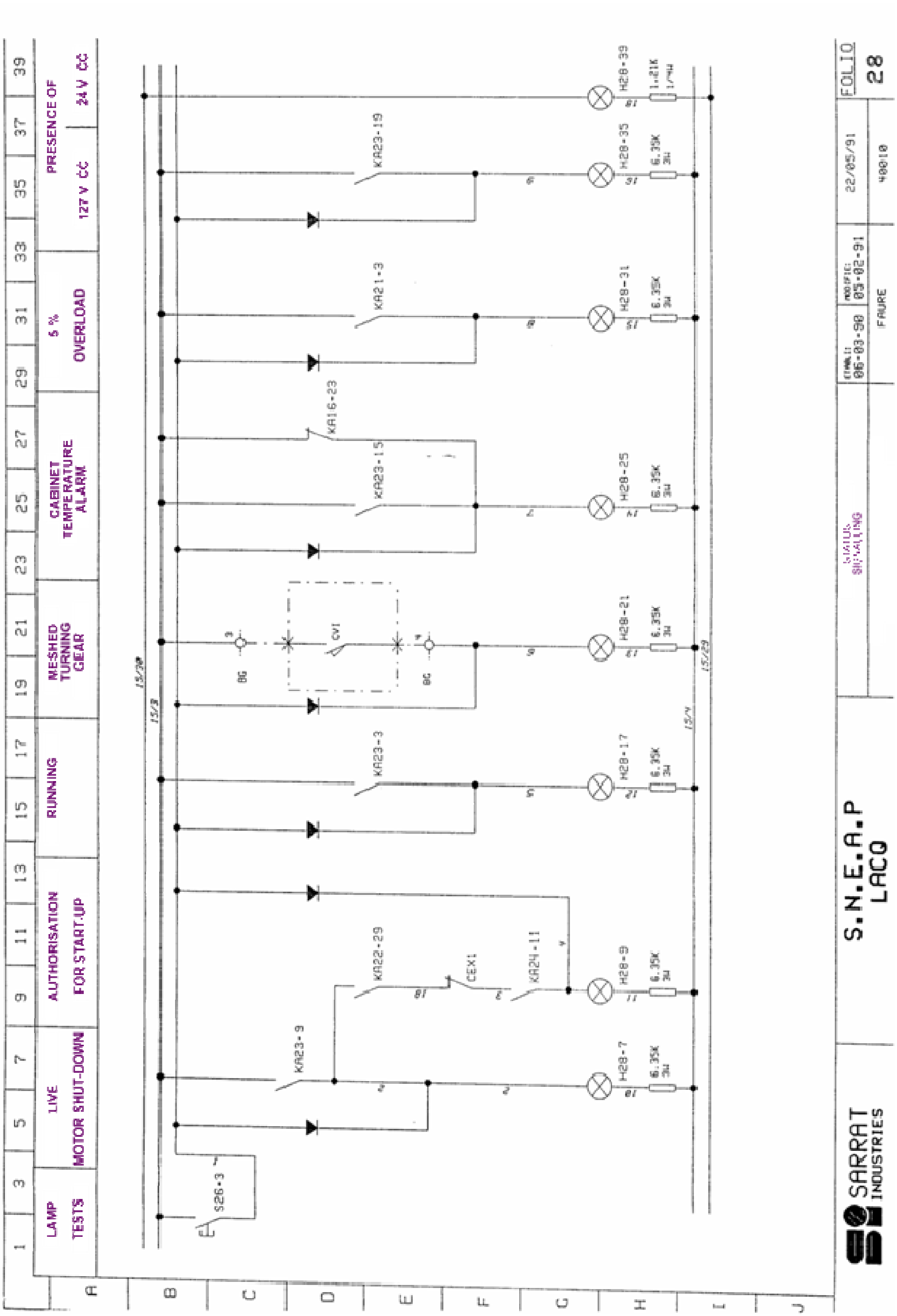


Figure 153: Synchronous motor control – Sheet 28

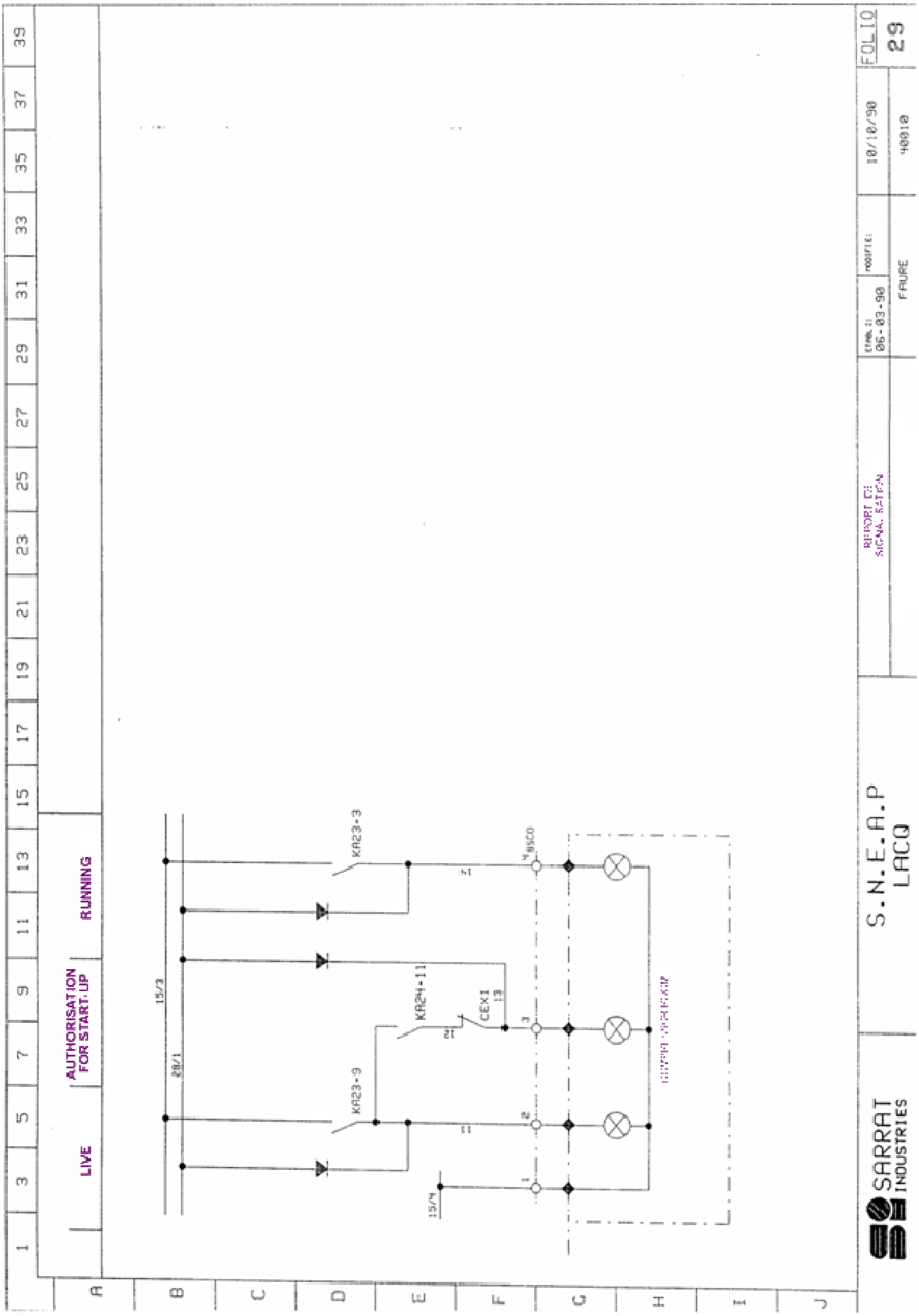


Figure 154: Synchronous motor control – Sheet 29

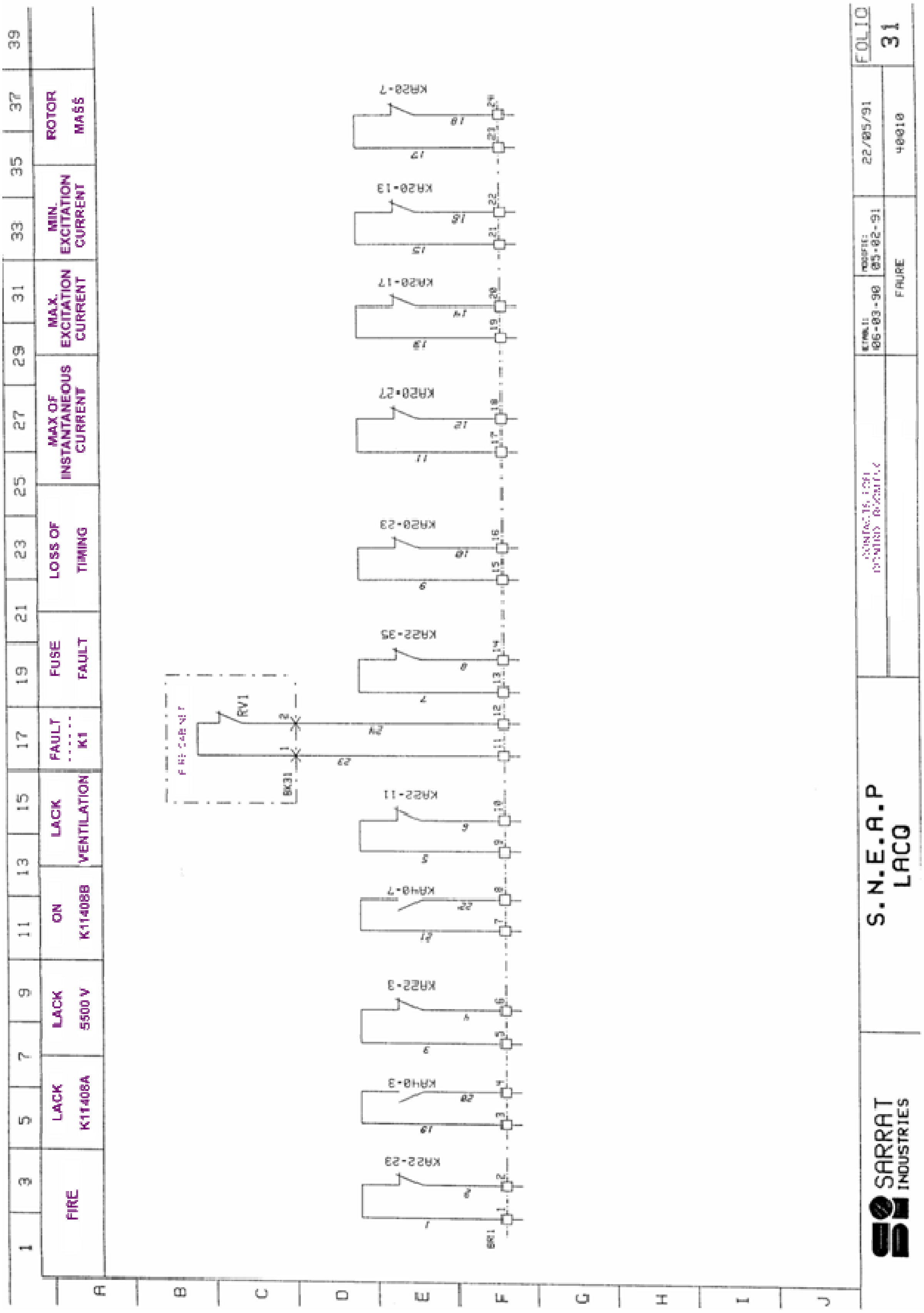


Figure 155: Synchronous motor control – Sheet 31

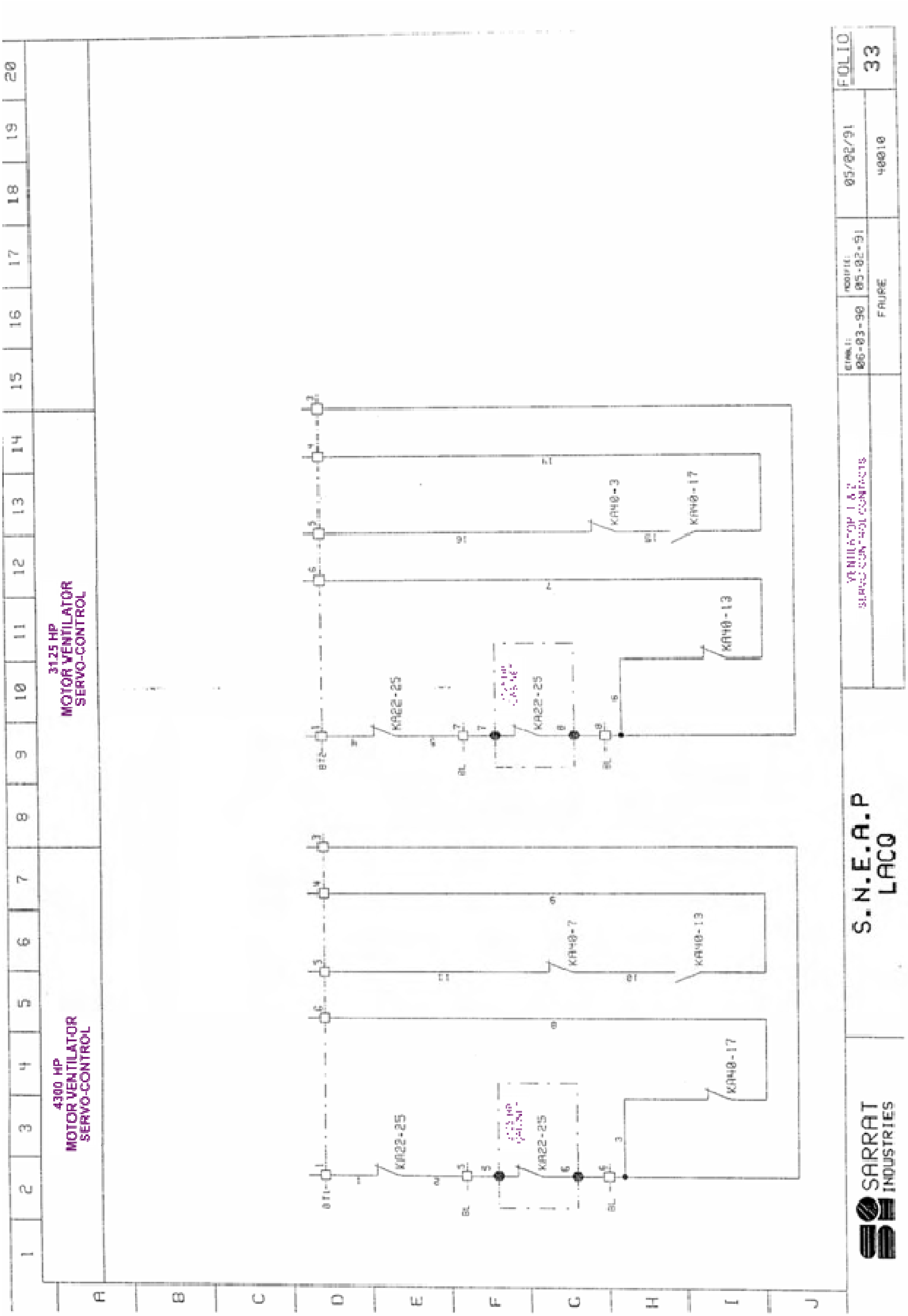


Figure 156: Synchronous motor control – Sheet 33

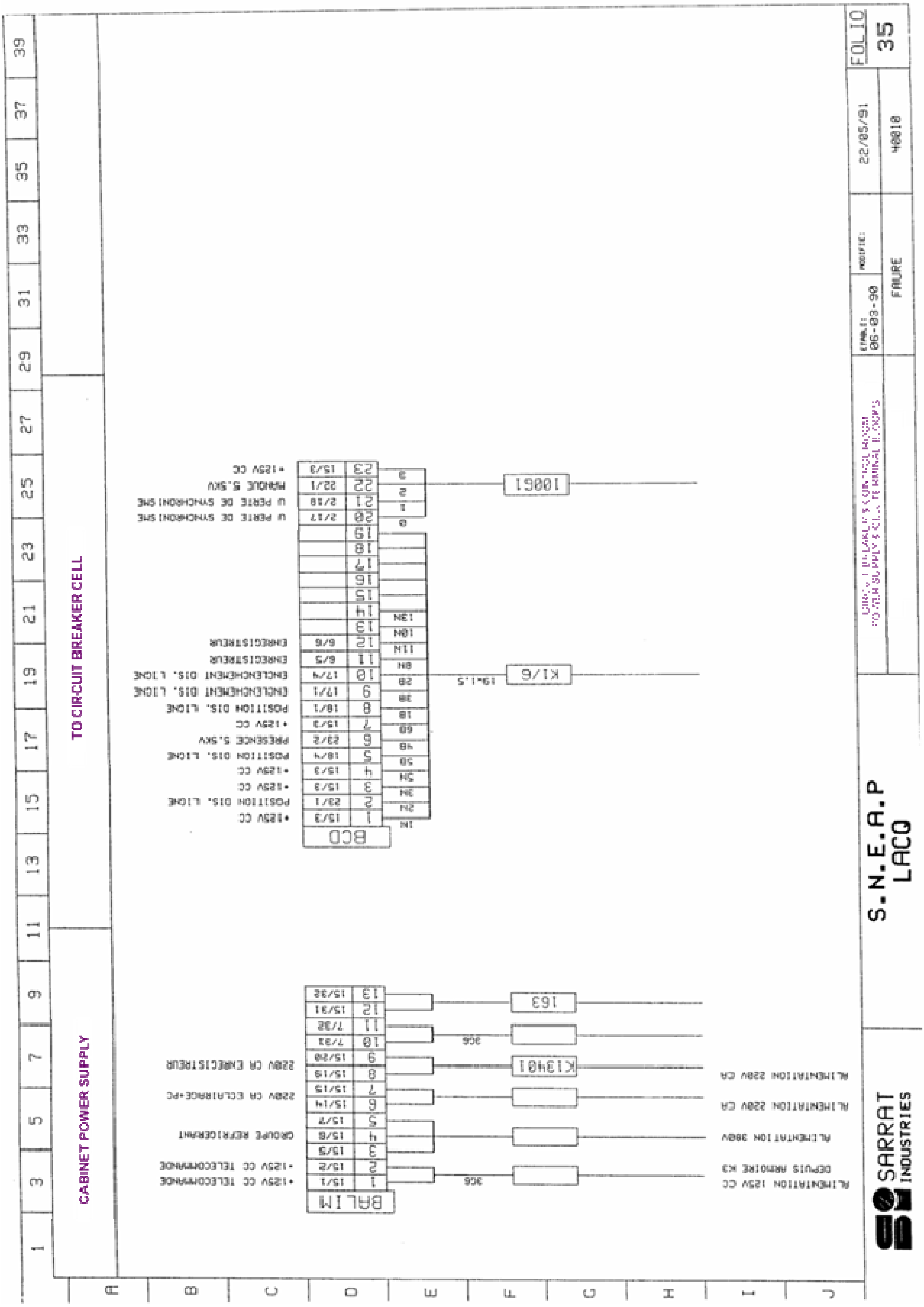


Figure 157: Synchronous motor control – Sheet 35

Sheet 40: Fan control and faults relaying
Supply between bars 15/37 and 15/38 (from breaker Q15 on sheet 14 col.21)

Sheet 41: Fan 1 control circuit

Sheet 42: Fan 2 control circuit
Copy as per sheet 41 but with tags and numbering for the second fan

Sheet 43: Indicator panel (lamps)
Layout plan

Sheet 44: Listing

Folio 45: Listing

Sheet 45: Layout of equipment in control cabinet
Not copied

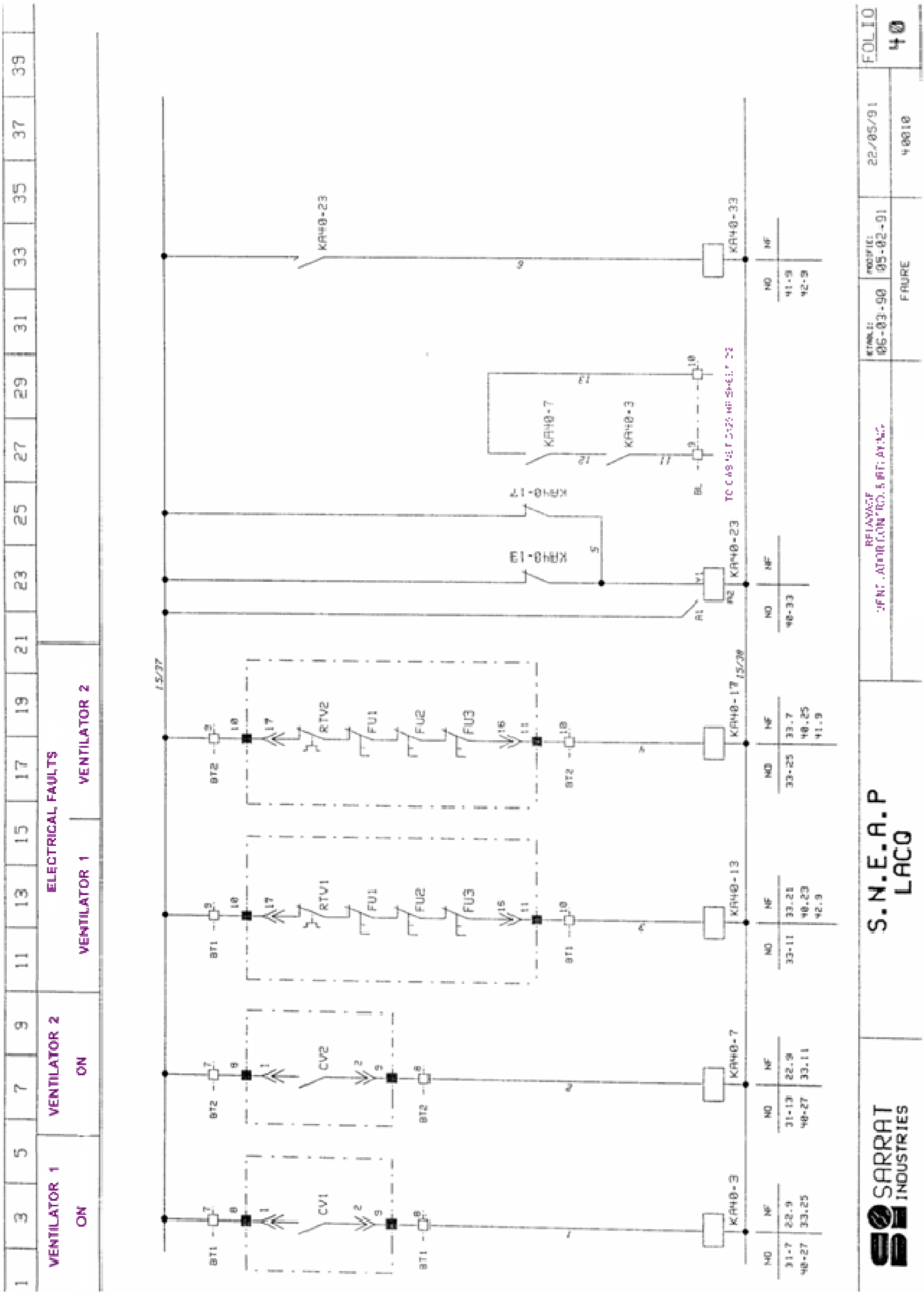


Figure 158: Synchronous motor control – Sheet 40

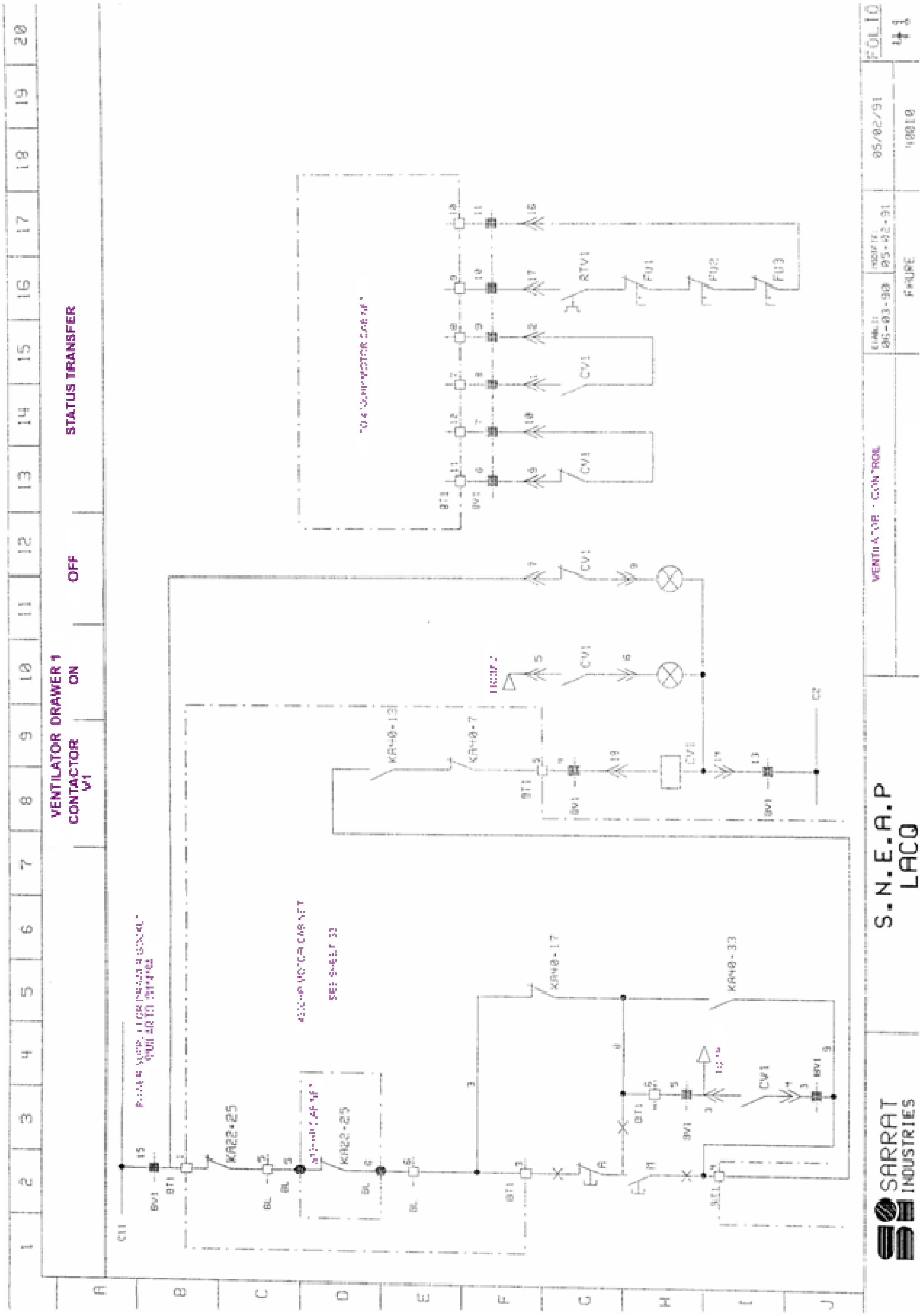


Figure 159: Synchronous motor control – Sheet 41

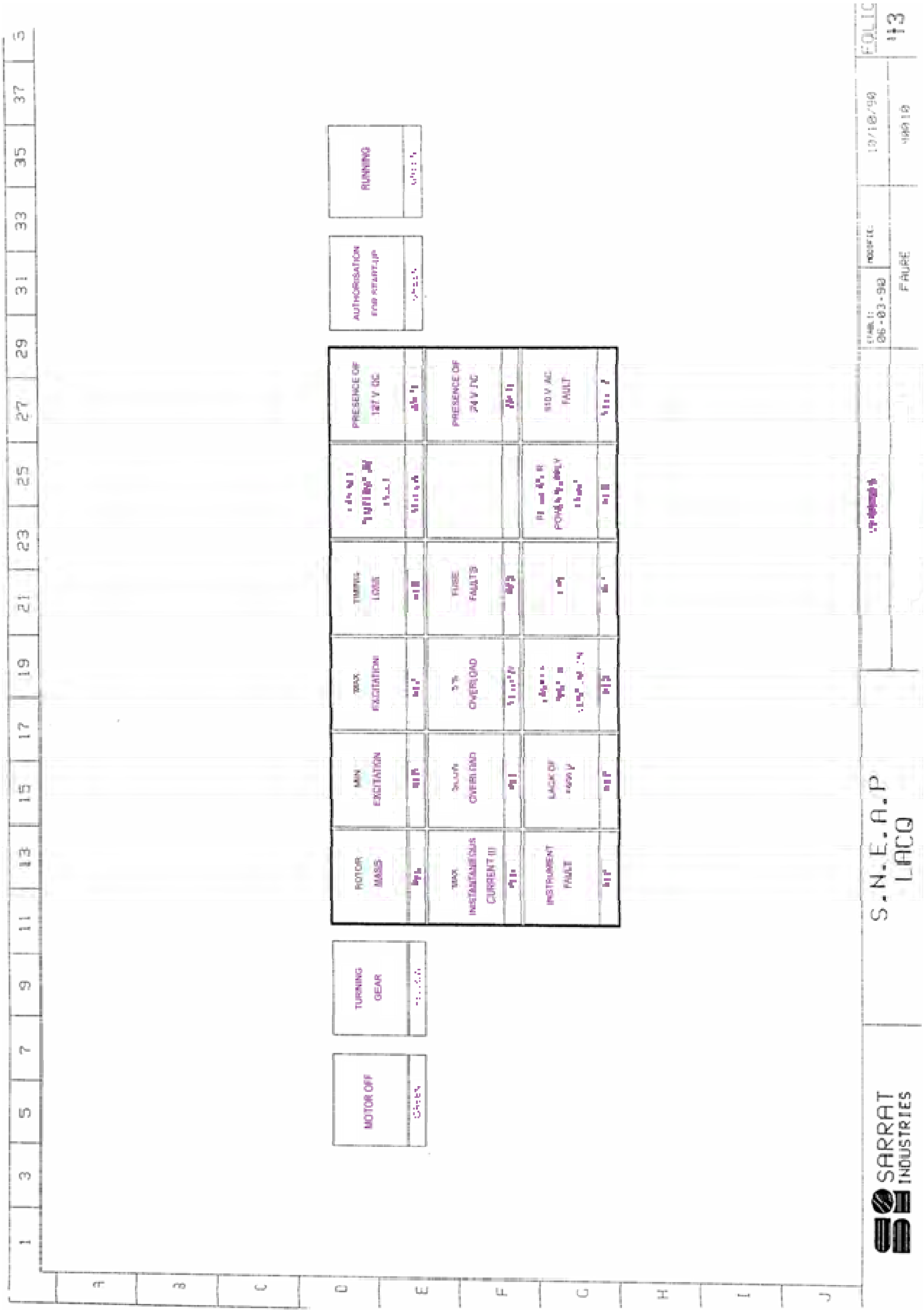


Figure 160: Synchronous motor control – Sheet 43

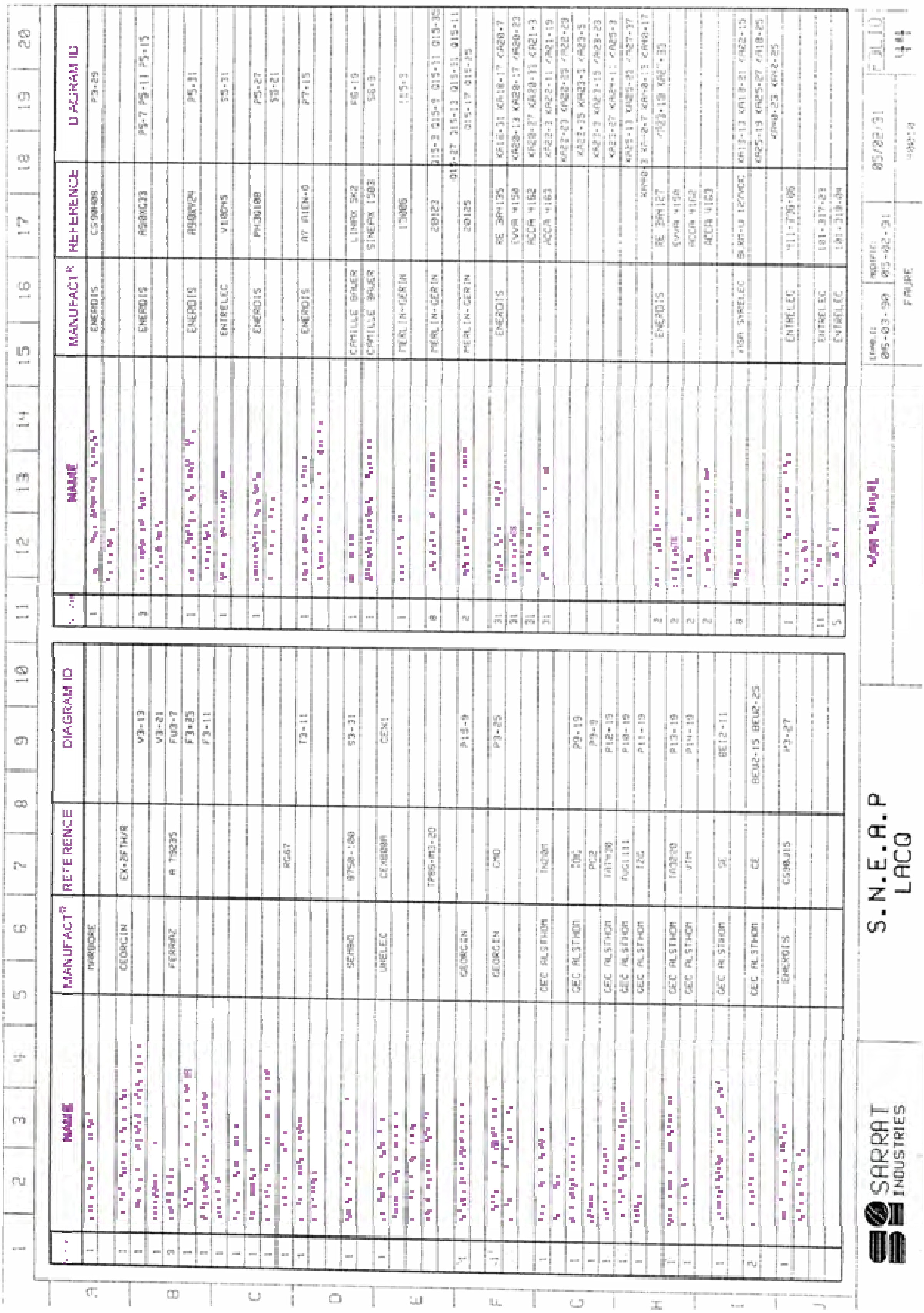
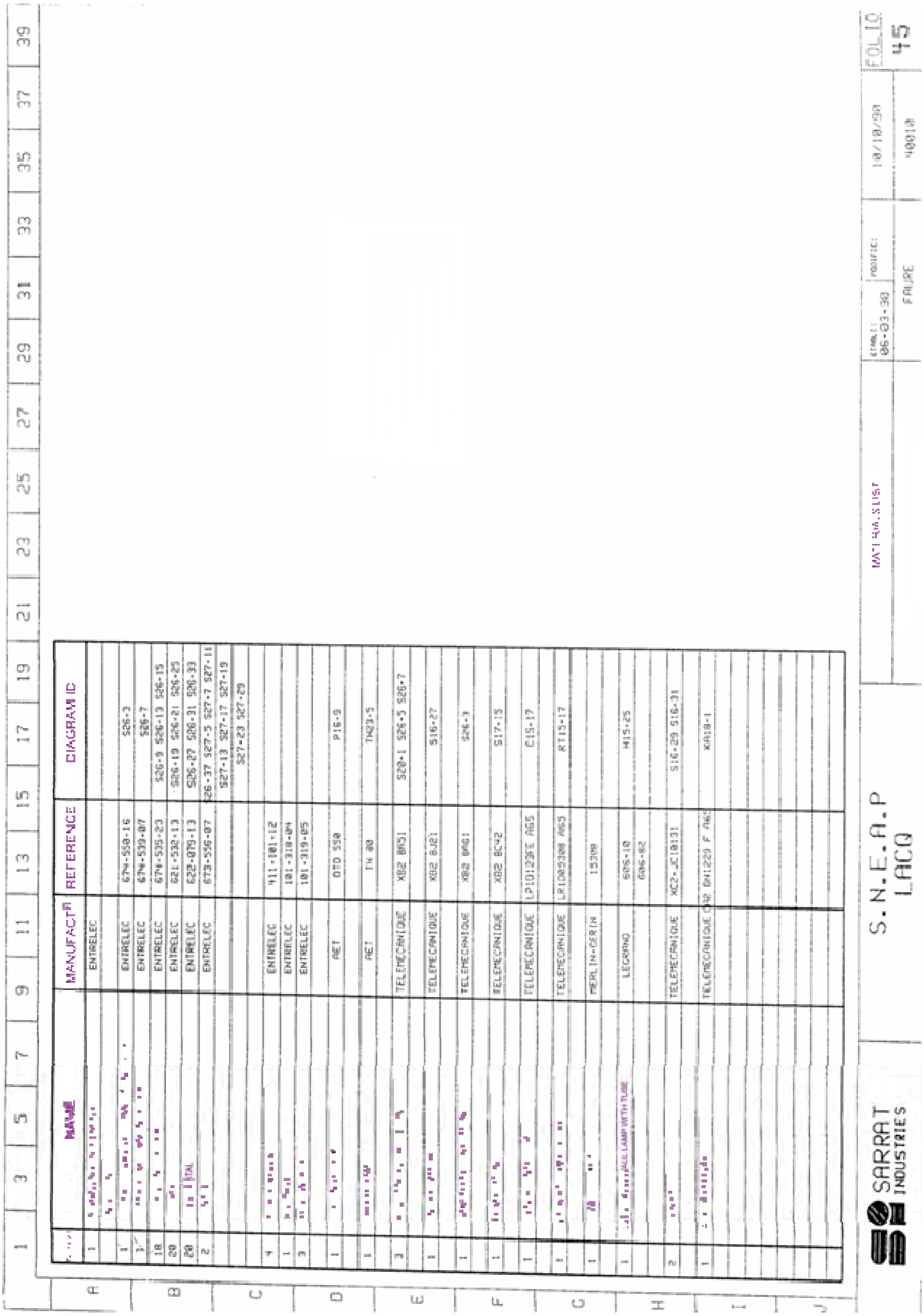


Figure 161: Synchronous motor control – Sheet 44



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14. GLOSSARY

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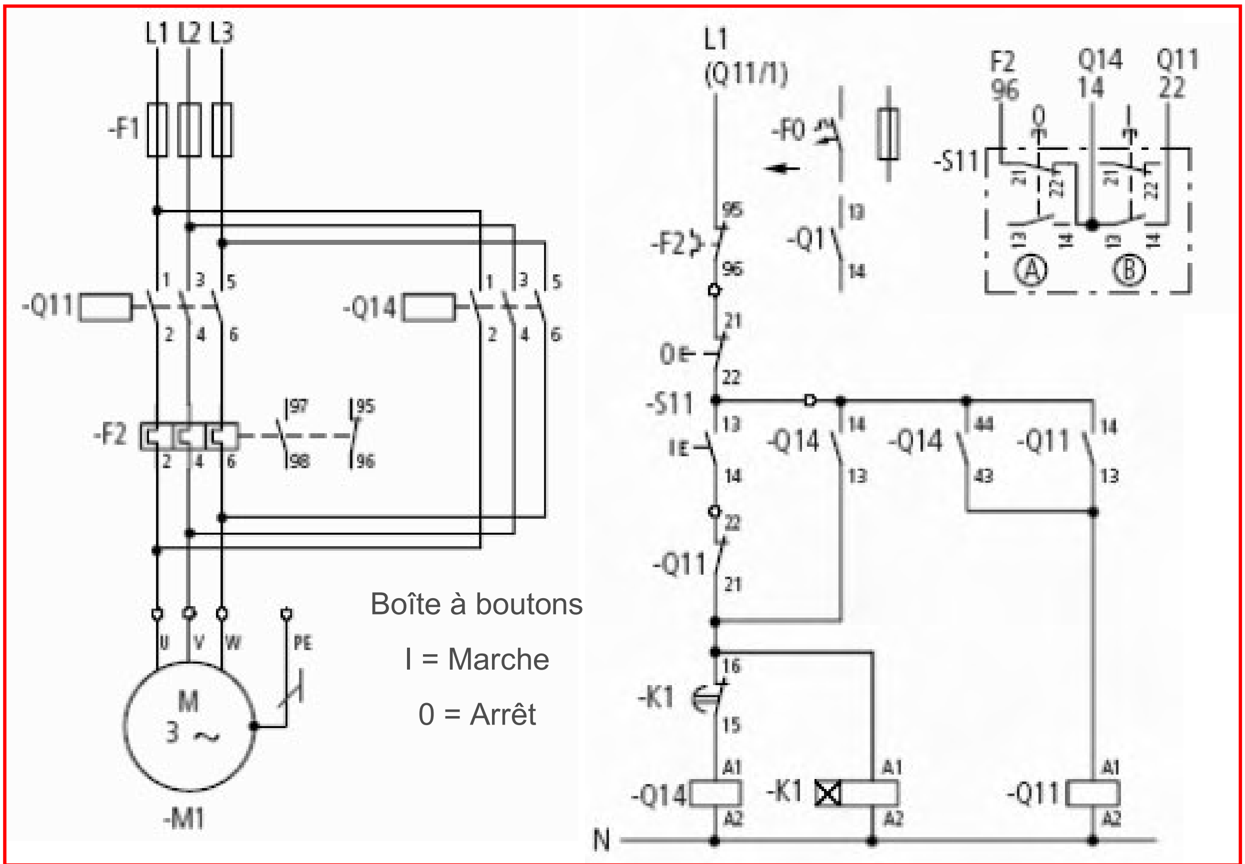
17. CORRECTIONS TO EXERCISES

1. One-way motor, with one Run – Stop control panel, with protection thermal relay ‘shunting’ during starting (for a certain time)

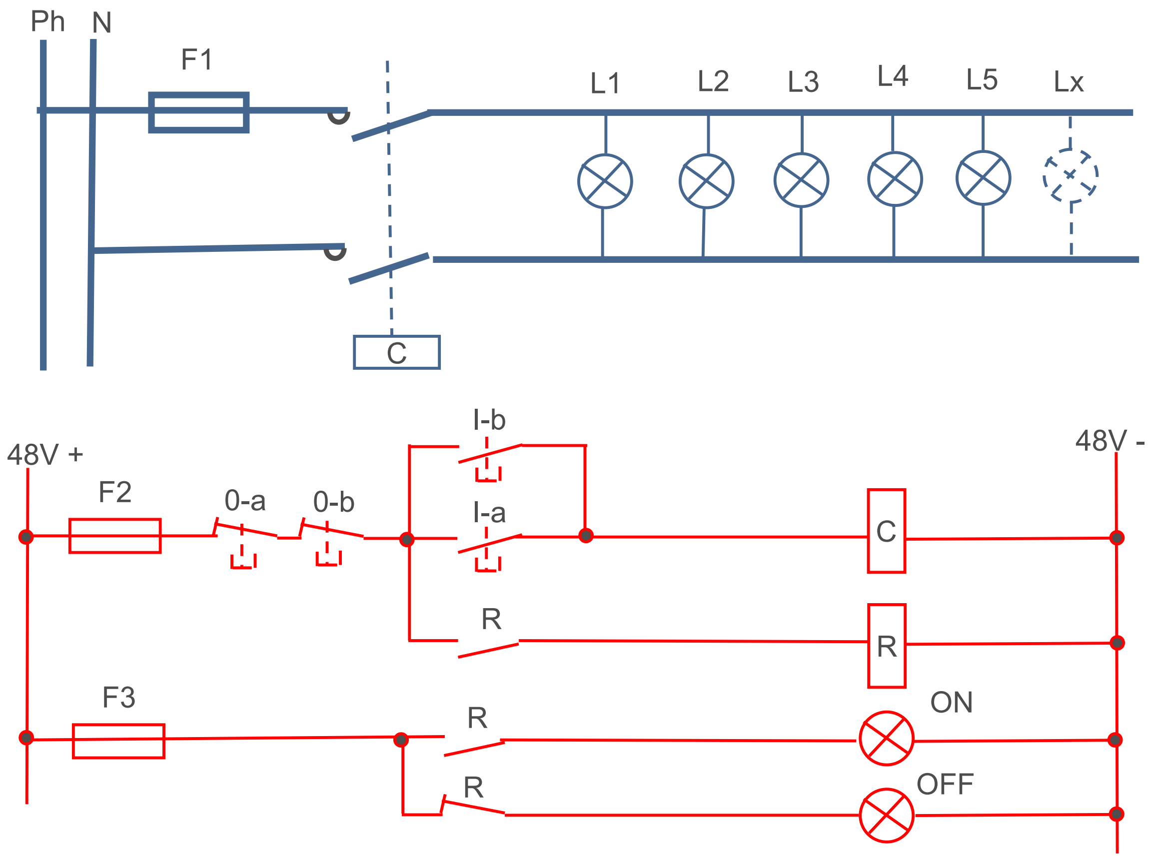


Completed control circuit

Q14: shunting contactor
K1: time-lag relay
Q11: line contactor

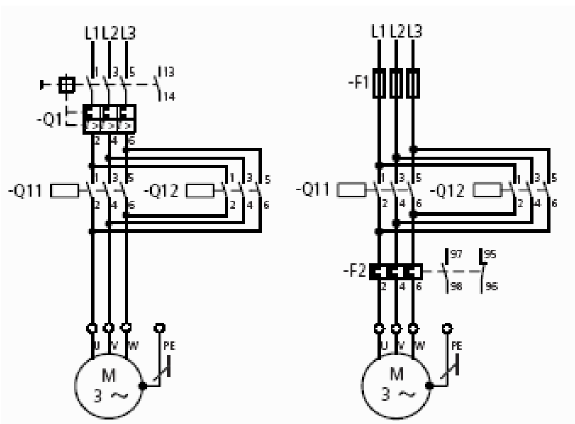
2. Here is a 'lighting' power circuit.

Complete the control circuit, if we know that contactor 'C' does not have an auxiliary contact, and self-power supply and indications are handled by 'R', F2 protects the coils and F3 the lamps.



Not forgetting the connection points…

3. Here are 2 power circuits for the same function, yet they are different. Define both types of starting, 'A' on the left and 'B' on the right



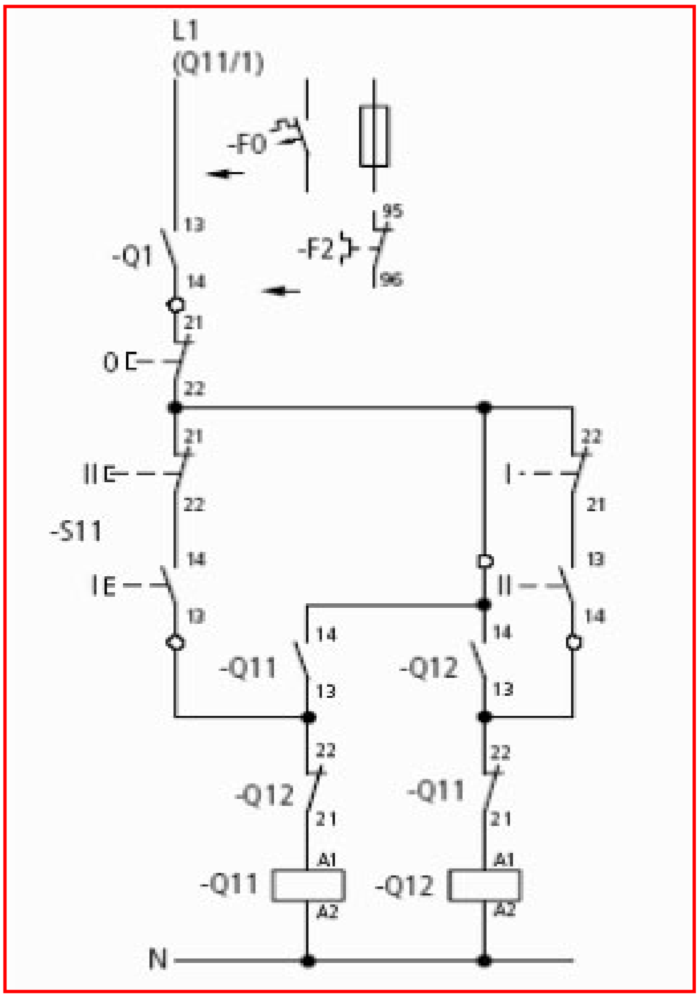
Both diagrams are for a two-way motor with 2 contactors

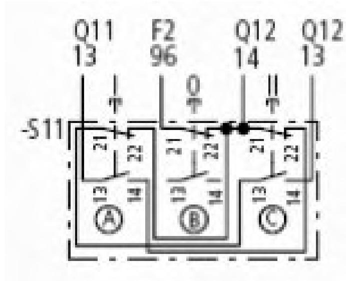
A: short-circuit and overload protection by motor breaker

B: short-circuit protection by fuses (and contactor), and overload protection by thermal relay (and contactor)

Be sure to distinguish these 2 methods

4. Complete the control diagram below





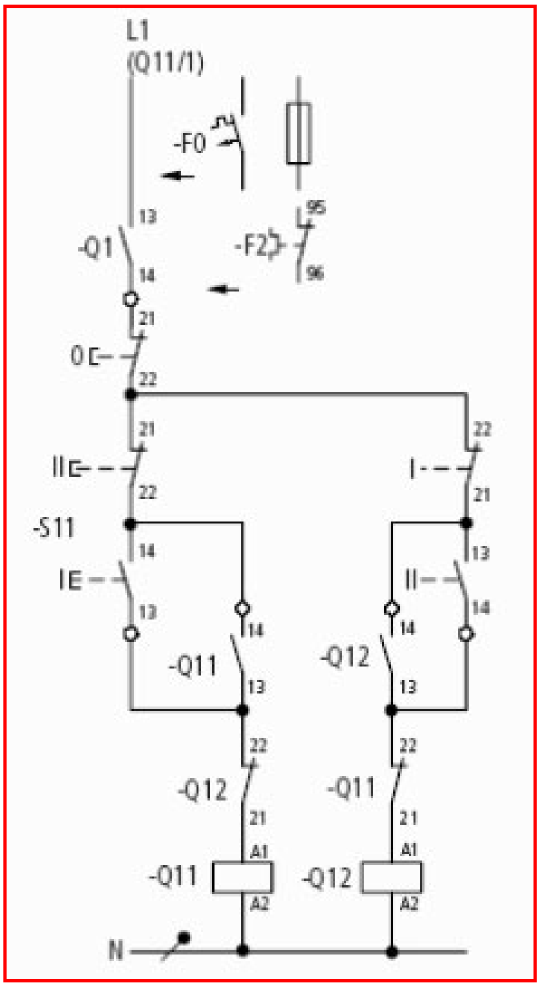
Direction of running reversed ***after*** ***stop button*** (button 0) pressed)

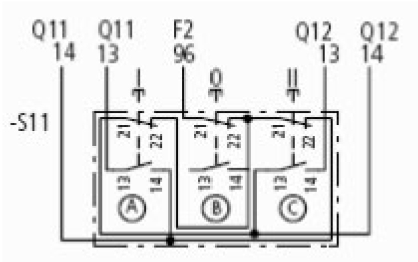
Q11 : line contactor, right-hand running

Q12 : line contactor, left-hand running

Control panel (S11)
I = right-hand running
0 = stopped
II = left-hand running
The control panel is represented in wire form to help you; NB we use the run buttons' NO and NC.

5. Complete the control diagram below





Direction of running reversed ***without stop button*** (button 0) ***being pressed***

Q11: line contactor, right-hand running

Q12 : line contactor, left-hand running

Control panel (S11)
I = right-hand running
0 = stop
II = left-hand running
The control panel is represented in wire form to help you; NB we use the run buttons' NO and NC.

Le contact NF ‘F2’ est supposé incorporé après Q1

This looks like the previous exercise, but it is different!

Operation for exercises 3 and 4;

Fonctionnement : L'actionnement du bouton-poussoir I provoque l'excitation de la bobine du contacteur Q11. Le contacteur enclenche le moteur en marche à droite et reste sous tension après relâchement du poussoir I par son propre contact auxiliaire Q11/14-13 et par le bouton 0 (contact impulsionnel). Le contact à ouverture Q11/22-21 verrouille électriquement le contacteur Q12. L'actionnement du bouton-poussoir II enclenche le contacteur Q12 (marche à gauche du moteur). Pour passer de la marche à gauche à la marche à droite, il faut, selon le schéma, actionner au préalable le bouton 0 ou actionner directement le bouton correspondant. En cas de surcharge, la coupure s'opère par le contact à ouverture 95-96 du relais thermique F2 ou par le contact à fermeture 13-14 du relais thermique ou du disjoncteur.

6. Star-triangle starting

Explain / describe the power circuit

Pushbutton 'I' actuates the time-lag relay K1, whose make contact K1/17-18, acting as an instantaneous contact (coil on K1 has operating delay), feeds star contactor Q13. The break contact Q13/21-22 opens the circuit of coil Q15, (electrically) locking the closure of this contactor. In the same circuit, **time-lag contact** K1/17-18 has remained open (100 ms is sufficient) to prevent action on Q15. Q13 when excited feeds line contactor Q11 via make contact Q13/13-14. Q11 and Q13 are self-powered via make contacts Q11/13-14 and Q1/43-44. Q11 feeds motor M1 via star coupling.

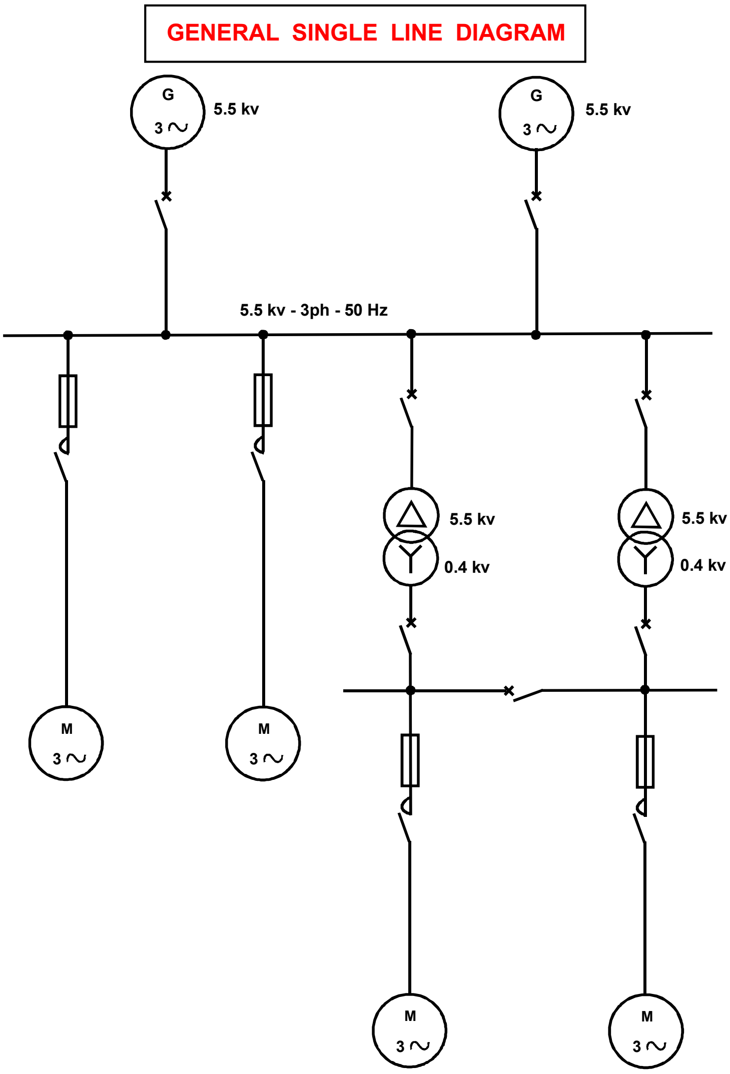
After the delay has elapsed (coil), contact K1/17-18 opens the Q13 circuit. Contact Q13/21-22 re-closes, unlocking Q15, which is excited (with contact K1/17-18 closed, and relay K1 still excited). Since star contactor Q13 has reopened, the triangle contactor Q15 is called, and couples motor M1 with the full voltage.
At the same time, break contact Q15/21-22 interrupts the Q13 circuit, thereby locking star operation.
Restarting is only possible after cut-out using the '0' pushbutton, or in case of overload, via the break contact 95-96 on thermal relay F2 or break contact on motor breaker Q1/21-22 or break contact of motor breaker Q1/13-14 (instead of the thermal relay)

7. Star-triangle starting

Explain / describe the power circuit

Pushbutton 'I' actuates star contactor Q13, whose make contact Q13/13-14 feeds the line contactor Q11. Q11 is called, and couples motor M1 in star configuration. Q11 and Q13 are self-powered via make contact Q11/13-14, and Q11 is also self-powered via Q11/43-44 and the '0' pushbutton. At the same time, time-lag relay K1 is fed with the line contactor Q11.
After the set time has elapsed, K1 opens the Q13 circuit via change-over contact 15-16, and closes the Q15 circuit via 15-18. Star contactor Q13 reopens. Triangle contactor Q15 is called, and couples motor M1 with the full voltage. At the same time, break contact Q15/21-22 interrupts the Q13 circuit, thereby locking star configuration restart and/or operation.
Restarting is only possible after cut-out using the '0' pushbutton, or in case of overload – as in the description in the previous exercise.

8. Draw the one-line equivalent of the diagram below


GENERAL SINGLE LINE DIAGRAM
G
3 ~
5.5 kv
G
3 ~
5.5 kv
5.5 kv - 3ph - 50 Hz
5.5 kv
0.4 kv
5.5 kv
0.4 kv
M
3 ~
M
3 ~
M
3 ~
M
3 ~

9. Using the Karnaugh map, simplify the following logic equation:

$$T = \bar{a}b\bar{c}\bar{d} + ab\bar{c}\bar{d} + \bar{a}bc\bar{d} + abc\bar{d} + \bar{a}\bar{b}c\bar{d} + a\bar{b}c\bar{d}$$

T: cd \ ab	00	01	11	10
00	0	1	1	0
01	0	0	0	0
11	0	0	0	0
10	1	1	1	1

$$T = b\bar{d} + c\bar{d}$$

10. Using the Karnaugh map below, find the reduced logic equation.

U: cd \ ab	00	01	11	10
00	1	1	1	1
01	1	1	1	1
11	1	1	0	1
10	1	1	1	1

Il suffit ici de prendre le 0 et de passer par le théorème de DE MORGAN.

$\bar{U} = abcd$

$U = \bar{\bar{U}} = \overline{abcd}$

$U = \bar{a} + \bar{b} + \bar{c} + \bar{d}$

$$U = \bar{a} + \bar{b} + \bar{c} + \bar{d}$$

11. Which representation do we use to represent logic functions in diagram form?

Logic diagram

12. Which is the logic function described as follows: in its three-variable truth table (*a*, *b* and *c*), the output column only has one 1, when the three variables are at 0.

NOR function

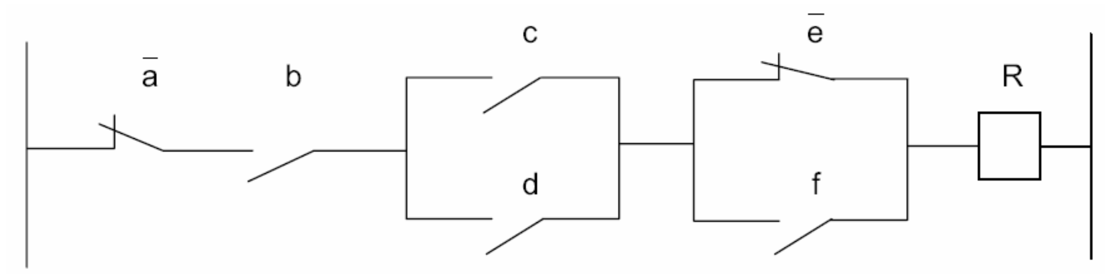
13. Which function is described here: in its three-variable truth table (*a*, *b* and *c*), the output column only has one 0, when the three variables are at 1.

NAND function

14. Karnaugh maps are primarily used:

To simplify logic equations

15. Convert the contacts diagram to logic equation form:



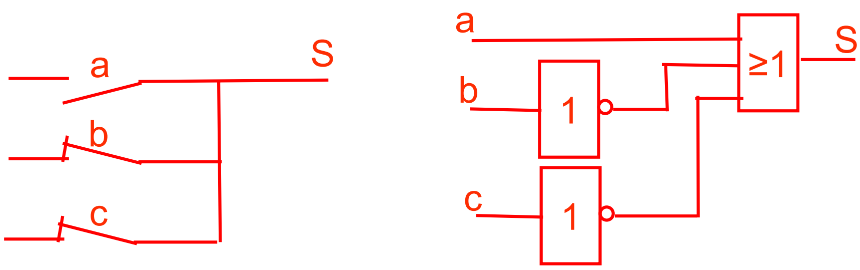
$$R = \bar{a}.b.(a+d).(\bar{e}+f)$$

16. Knowing that $S = a + \overline{b \cdot c}$, represent the contacts diagram and logic diagram

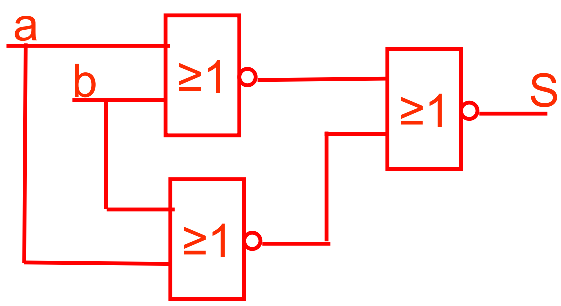
No problem with the contact diagram; it is the direct image of the equation. For the logic diagram, we need to use the de Morgan theorem

De Morgan theorem: $\overline{b.c} = \bar{b}+\bar{c}$

As the "complemented product" is not logical in representation (AND function with b.c and NOT function at output, to return to an AND with a.), and we gain a function



17. Plot an OR function with NOR functions.

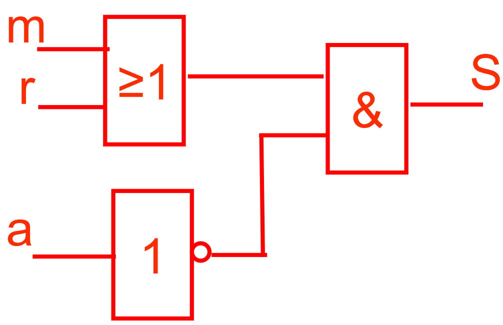


18. Plot the logic diagram of the logic equation

$$R = (m + r) \cdot \overline{a}$$

using OR, AND, NOT functions.

Direct application



using only NAND functions.

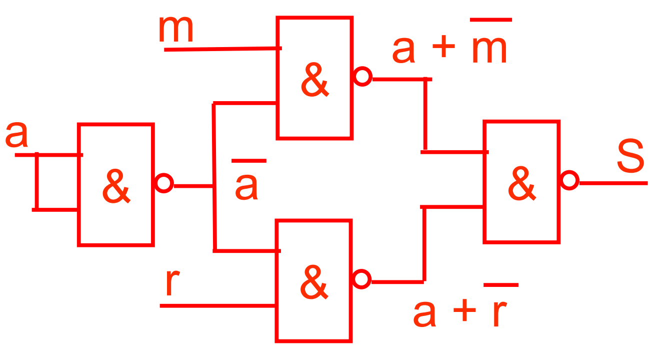
We need to use a "relay"

$$S = (m+r).\overline{a} = m.\overline{a} + r.\overline{a}$$

Input to end NAND gate is $\overline{m.\overline{a}}$ and $\overline{r.\overline{a}}$

Using de Morgan's theorem: $\overline{m.\overline{a}} = a + \overline{m}$ and $\overline{r.\overline{a}} = a + \overline{r}$

The same applies to the upstream step



19. Based on the truth table below, find the equation for the output S (without reducing the equation).

a	b	c	S
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	0

$$S = \bar{a}.\bar{b}.\bar{c} + \bar{a}.b.\bar{c} + a.\bar{b}.c$$

20. Based on the Karnaugh map below, find the reduced logic equation.

R (cd \ a b)	00	01	11	10
00	1	0	0	1
01	1	0	0	1
11	1	0	0	1
10	1	0	0	1

We could write the complete equation and reduce it, but with the grouping, we can see that the 3 variables a, c and d change state when b remains at '0'

Therefore $R = \bar{b}$

21. Simplify the logic equation below:

$$T = \bar{a}b\bar{c}\bar{d} + ab\bar{c}\bar{d} + \bar{a}bc\bar{d} + abc\bar{d} + \bar{a}\bar{b}c\bar{d} + a\bar{b}c\bar{d}$$

Algebraically

Let's put d (bar) as a common factor to simplify writing

$$T = \bar{d}\,(\bar{a}.b.\bar{c} + a.b.\bar{c} + \bar{a}.b.c + a.b.c + \bar{a}.\bar{b}.c + a.\bar{b}.c)$$

Then we group products with a variable changing state, (which is cancelled out) when another variable (or maybe several variables) does not change
New equation

$$T = \bar{d}\,(b.\bar{c} + b.c + \bar{b}.c)$$

New grouping on this level, but beware!! Why only assume for instance that 'b' is fixed with 'c' varying, as opposed to the other way round ('c' fixed with 'b' varying); we need to take the 2 possibilities, as the 'b.c' function can be counted + 2 times; that doesn't change anything in the equation – *An element should not be left on its own when it can be associated -*

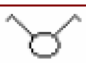
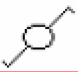
This gives us the final equation:

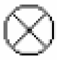
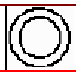
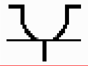
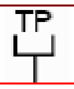
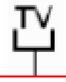
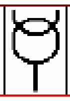
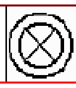
$$T = \bar{d}\,(b+c) = \bar{d}.b + \bar{d}.c$$

Compare with exercise 9; the result is the same as with the karnaugh map, and with the karnaugh method, it is clear that we associate variables 'b.c' twice when both are at '1', together…………….

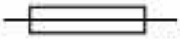
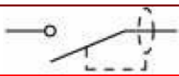
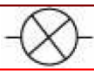
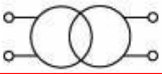
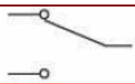
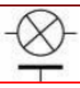
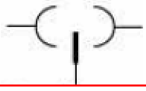
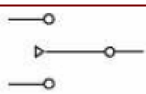
22. As you know the symbols from the previous course (MN-SE010), identification in the table below should be child's play…

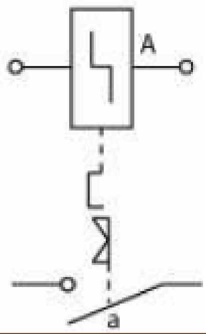
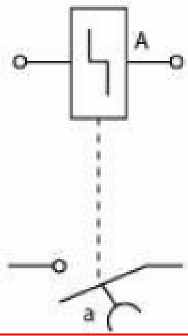
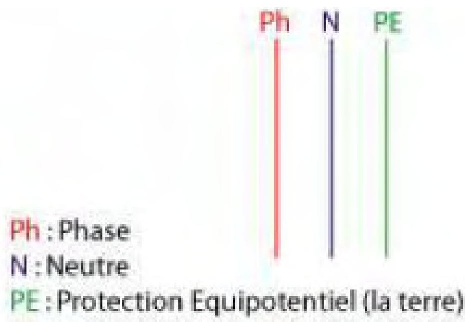
And even if certain symbols may not (apparently) be familiar, you should still have no problems. As for the description, the terms used, things might be slightly different.

Symboles	Votre réponse
	One-way switch
	Two-gang one-way switch
	Two-way switch

 or 	Lighting point
	Pushbutton
	2P + E socket with clip
	Telephone socket
	Television socket
	Safety socket (with transformer)
	Heater
	Luminous pushbutton

23. Identify these symbols taken from a diagram

Symboles	Votre réponse
	Fuse
	Switch
	Differential switch
	Current socket
	Lamp
	Transformer
	Pushbutton
	Two-way switch
	Lamp with earth (to be connected)
	Current socket with earth (earth obligatory universally with the latest regulations)
	2-way switch with central stop

		
Remote control switch	Timer	Single-phase supply Ph+N+E