# CHAPTER 3
# TECHNICAL DOCUMENTATION

*Lecture material for TTK 4175 Instrumentation Systems and Safety at the Department of Engineering Cybernetics, Norwegian University of Science and Technology (NTNU).*

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**The essence of technical documentation?**
*Illustration generated by Microsoft Copilot (powered by OpenAI), July 2025.*



The content is updated regularly to improve precision and ensure relevance, which is reflected in the revision number. Please reach out to mary.a.lundteigen@ntnu.no if you have comments or suggestions for improvement.

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# 3 Technical documentation

Understanding and interpreting technical documentation is essential for engineers. Technical documentation encompasses specifications, analyses, drawings, equipment lists, test reports, and schematics that describe how an instrumentation system is specified, designed, installed, and operated.

Besides providing essential information about the system's technical details and installed environment, technical documentation is key to understanding the underlying assumptions behind the technical choices made and to maintaining traceability from requirements to their implementation.

Technical documentation often contains information originating from different engineering disciplines and serves as common ground for communicating such details across disciplines during design, installation, operation, and maintenance. The inability to interpret technical documentation correctly can lead to misunderstandings that may eventually make systems unsafe or cause unacceptable downtime.

This chapter provides insights into a selection of technical documents that automation engineers are expected to know about and (most likely) will use in a future job.

## 3.1 Abbreviations

(a selection)

| | |
|---|---|
| ANSI | American National Standards Institute |
| C&E | Cause and effect |
| ESD | Emergency shutdown (system) |
| F&G | Fire and gas (system) |
| IEC | International Electrotechnical Commission |
| ISO | International Organization for Standardization |
| ISA | International Society of Automation |
| NORSOK | NORsk SOkkels Konkurranseposisjon |
| P&ID | Piping and Instrument Diagram |
| PFD | Process flow diagram (here, not to be confused with: Probability of failure on demand) |
| PSD | Process shutdown (system) |
| SCD | System control diagram |

## 3.2 Documents in focus and their relationships

The chapter focuses on the following documents: some are specific to the processing industry, while others apply to other industry sectors as well:

- PFD – Process Flow Diagram
- P&ID – Piping and Instrument Diagrams
- SCD – System Control Diagrams
- Cause and effect (C&E) diagram
- Electrical Circuit Diagrams
- Instrument Loop Diagrams
- Pneumatic or Hydraulic Control Diagrams

Fig. 1 identifies relationships among the documents, showing that some serve as the basis for others. This chapter focuses on the shutdown hierarchy, which is covered in Chapter 6.

Many of the technical documents have "*diagram"* in their names, indicating that they are graphical and show relationships between equipment and functions. The listed documents are all created in the design phase and applied throughout the operational phase. For example, any modification to the hardware or software must result in updates to the relevant documentation. Keeping technical documents updated is crucial. Lack of updates may confuse operating personnel and technicians, potentially leading to hazardous situations and accidents.

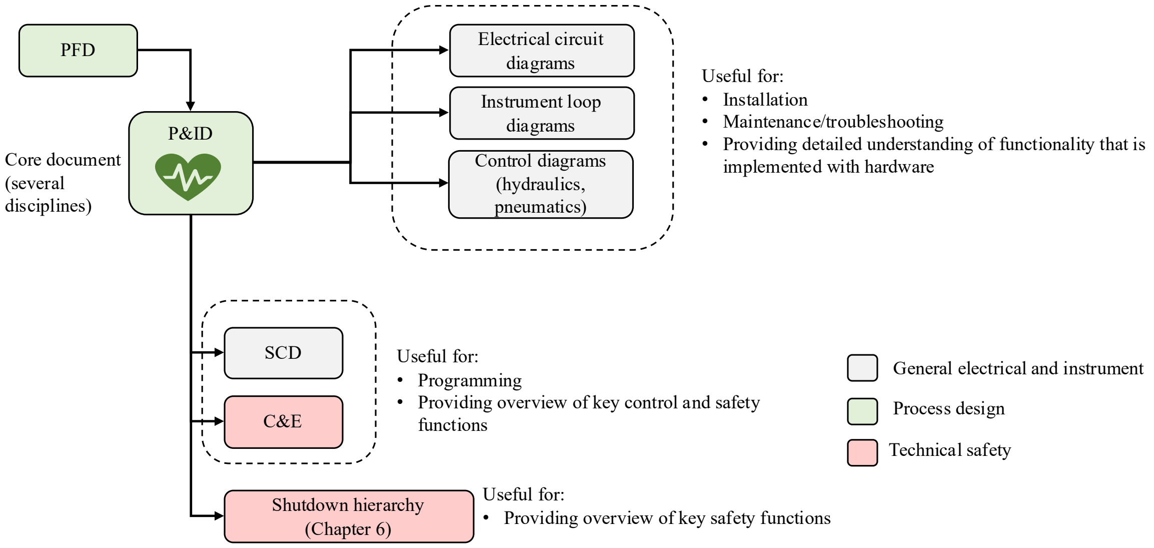



**Fig. 1. Overview of key technical documents**

## 3.3 Commonly used graphical symbols

We will start by introducing the process design documents. However, this requires some insight into how graphical symbols and coding are to be interpreted, with a focus on:

- Process-related equipment
- Sensors and transmitters
- Valves and valve actuators
- Pneumatic and hydraulic control valves
- Electrical components

International standards provide more detailed guidance on graphical symbols and coding used in technical diagrams than is presented here. Some important ones are:

- ISO 14617 on "Graphical symbols for diagrams" (15 parts /sub-standard) that covers a lot of symbols. An overview of all is provided in ISO 14617-1 (2005).
- ISO 15519 on "Specifications for diagrams for the process industry" (ISO 15519-1, 2010; ISO 15519-2, 2015)

While these standards provide a common framework, engineering companies and operators may adopt customized symbol sets or deviate from them to suit specific project or organizational needs. In such cases, a legend or symbol list is typically provided to ensure clarity and consistency in documentation.

### 3.3.1 Process system symbols

Examples of process equipment and systems, like pumps, compressors, turbines, heat exchangers, and vessels, are shown in Fig. 2.

- Pump symbols indicate the type of pump, with centrifugal pump symbols being the most common in the process industry.
- Compressors and turbines use similar trapezoidal symbols oriented in opposite directions to emphasize their different functions. While a compressor compresses the gas, the gas's specific volume decreases with increasing pressure, and is therefore depicted with the large end at the inlet and the small end at the outlet. A turbine reduces the pressure, thus increasing (or expanding) its specific volume, and is depicted with the small end at the inlet and the large end at the outlet.
- Coolers and heaters are usually identified by a circle (and/or rectangle) with pipes entering and exiting (in a closed loop) with either a heating or cooling medium, depending on the function.
- Process vessels are often of the type separators (separating fluids from gases), scrubbers (removing liquids from gas), or distillation columns (performing more granular extraction of

fluids and gases). Their orientation depends on the application, and the typical ones are shown. The circular ends indicate that the vessels are pressurized. Non-pressurized vessels often have flat tops and bottoms.

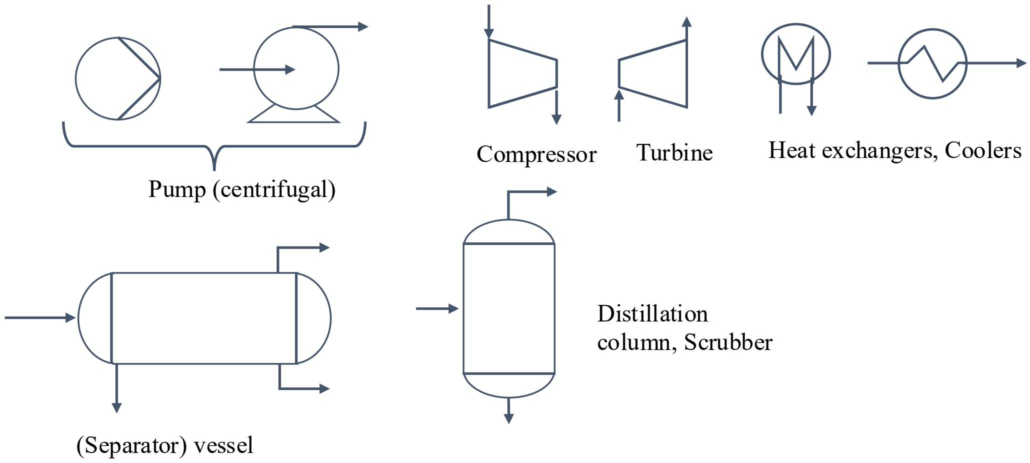



**Fig. 2. Symbols for process related equipment**

As mentioned, alternative ways to represent this equipment may exist, but they often share common layout features and structural conventions. These are added along with the technical documents.

## 3.3.2 Valves and actuators

Valves play an essential role in controlling and protecting processing systems. Understanding valve symbols is therefore essential. The valve symbols are generally split into two parts:

- Valve body – what is in contact with the fluids
- Valve actuator – what is causing the valve to change position

Fig. 3 illustrates typical symbols for valve bodies and actuators combined. Pictures have been added to show what they may look like in reality.

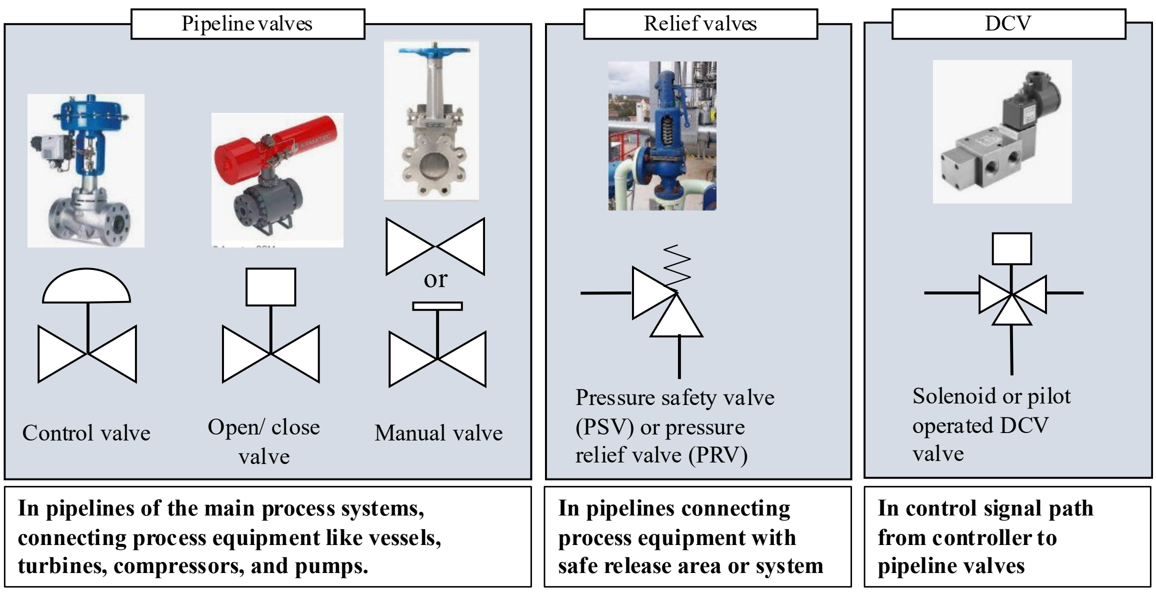



**Fig. 3. Valve types based on role and actuation mechanism**

The first three valves, referred to as pipeline valves, are the primary valves that controls flow between process equipment:

- Control valves: These valves can have an opening between 0 and 100%

- Open/close valves: These valves can be fully open or closed, but cannot be in a position between the two.
- Manual valve: A human operator decides the position, often fully open or closed, by using, e.g., a handwheel or other type of handle.

The way we distinguish the valves is by their top part or "hat", representing the valve actuator:

- Mushroom-like hat: The actuator controls the position between 0 and 100% opening, based on an external signal.
- Rectangle: Actuators change the position to open or closed in response to an external signal.
- Line or no actuator: Manually operated valves, requiring a person at the location to open and close them.

The pressure safety valve (PSV), also called the pressure relief valve (PRV), is a special case in which the actuation system is built into the valve itself.

- The PSV valves are installed in pipelines that connect process equipment (like general process pipelines and vessels) to a place where the process media can be safely exposed at high pressure. Such safe places can be:
    - Flare system with flare tower and associated piping arrangements (flammable gases, flammable toxic gases). In the flare, the gas is ignited, transforming it into non-explosive (and less toxic) components.
    - Absorption systems (scrubbers) and closed-loop containment with associated piping arrangements (toxic, but not flammable gases)
    - Directly to the surroundings (air, CO2)
- The purpose of the PSV is to quickly open when the pressure exposed to the valve from the connected process equipment reaches a preset threshold.
- There are two types of PSVs:
    - Pilot-operated PSV: A small tube (pilot line) routes process pressure to a mechanical, built-in pilot valve. Under normal operation, this pilot valve directs process pressure into a chamber above the main valve piston, using the process pressure to hold the valve tightly closed. When the pressure exceeds the mechanically calibrated setpoint, the pilot valve shifts position and vents (releases) the pressure from this upper chamber. This sudden loss of top pressure allows the high process pressure from underneath to push the piston up and open the valve.
    - Spring-loaded: This valve operates mechanically without any pilot lines or pilot valves. Instead, a heavy, calibrated steel spring exerts a continuous downward force to keep the valve closed under normal conditions. When the process pressure reaches the preset threshold, the gas's upward force overcomes the spring's resistance, lifting the valve disc (plug) off its seat to open the flow path.
- If the PSV fails to open, the process equipment may rupture. The threshold is therefore set with a safety margin below the maximum pressure the process equipment can tolerate.

The other special case in **Error! Reference source not found.** is the solenoid or pilot-operated directional control valve (DCV). The symbol shown in

- The DCV serves as the power (or signal) interface, converting commands from the electronic controller into the pressures required to open or close pneumatically or hydraulically operated pipeline valves.
- For larger pipeline valves, it may be necessary to arrange DCVs to power up in two steps, so that the first in line is operated by the controller's electrical signal, while the second is operated by the pressure set by the first.
- For this reason, the DCVs can be solenoid-operated (on signal from controller) or pilot-operated with pressure supplied (via a pilot line) from another, for example, solenoid-operated DCV.

DCVs are explained in more detail later, when the graphical symbols used for pneumatic and hydraulic circuit diagrams are covered.

**Error! Reference source not found.** has used the same valve body symbol for all three pipeline valves. However, the choice of valve body type depends on where and how it is used, including pressure conditions, tightness requirements, and fluid types. Therefore, some process diagrams apply symbols that more precisely identify the valve body type in Fig. 4. An illustration or picture of the valve bodies is shown above each symbol, as the symbol itself does not reveal what the valve interior looks like. However, it seems more common today to choose only one symbol, often the gate valve symbol, and instead look into the valve specification sheet to find its actual type.

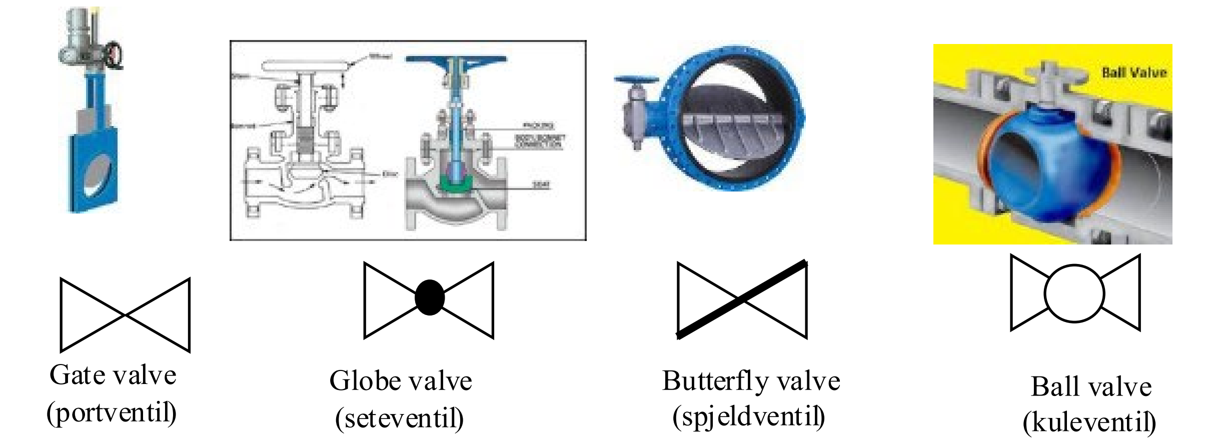



**Fig. 4. Graphical symbols for valve bodies**

A third special case is the unidirectional valves shown in Fig. 5. Two types of unidirectional valves are shown, each type with two commonly used symbols:

- Unidirectional valves for process pipes and pipelines: A flap, disc, or hinged plate opens when fluid flows in the permitted direction and generates sufficient force to overcome the valve's closing force (typically gravity, spring, or backpressure). If the flow reverses, the flap closes and prevents backflow.
- Unidirectional valves for hydraulic and pneumatic circuits: A ball-and-spring arrangement performs the same function. In the permitted flow direction, the fluid pressure pushes the ball away from its seat and compresses the spring, creating a flow path through the valve. When the pressure decreases or the flow attempts to reverse, the spring and reverse pressure force the ball back onto its seat, closing the valve and preventing flow in the opposite direction.

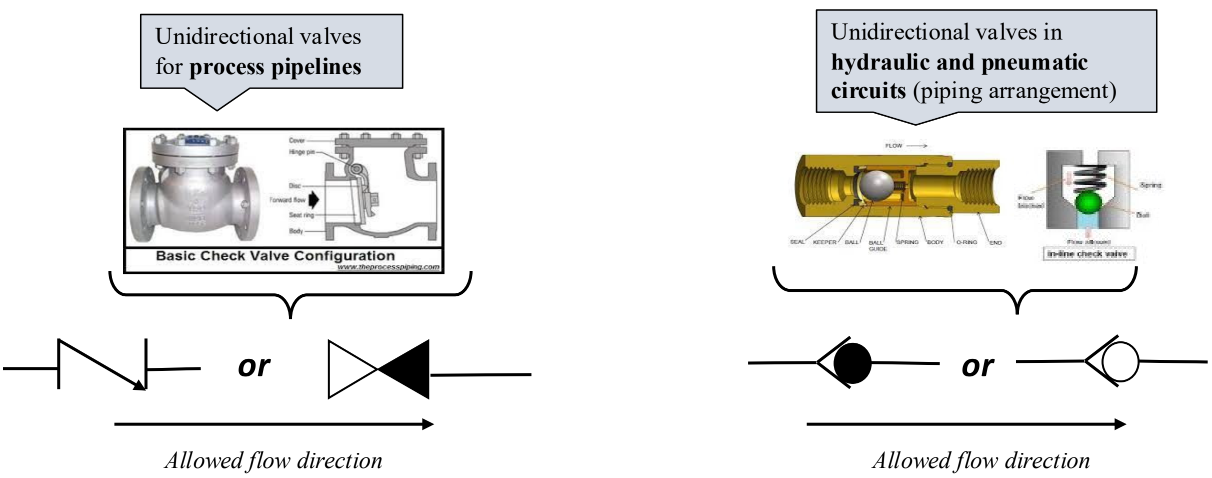



**Fig. 5. Unidirectional valve symbols**

## 3.3.3 Signal transmission symbols

Technical diagrams will often distinguish how signals are transmitted from sensors to controllers and from controllers to actuated devices, such as valves. Some of the most common graphical symbols for signal transmission are shown in Fig. 6 and the legend is (more or less) aligned with ISO 14617-3 (2002).

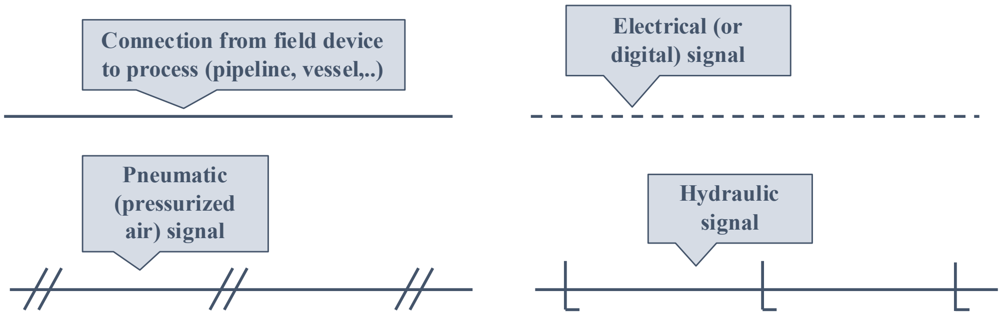



**Fig. 6. Signal transmission symbols**

## 3.3.4 Instruments and controllers

Process diagrams need to identify the most important instrumentation involved in measurement, control, and safety functions. The field instruments have connections to process equipment and pipelines that must be identified, and it is important for analysis of the process system operation to understand how they are involved in process equipment, often valves.

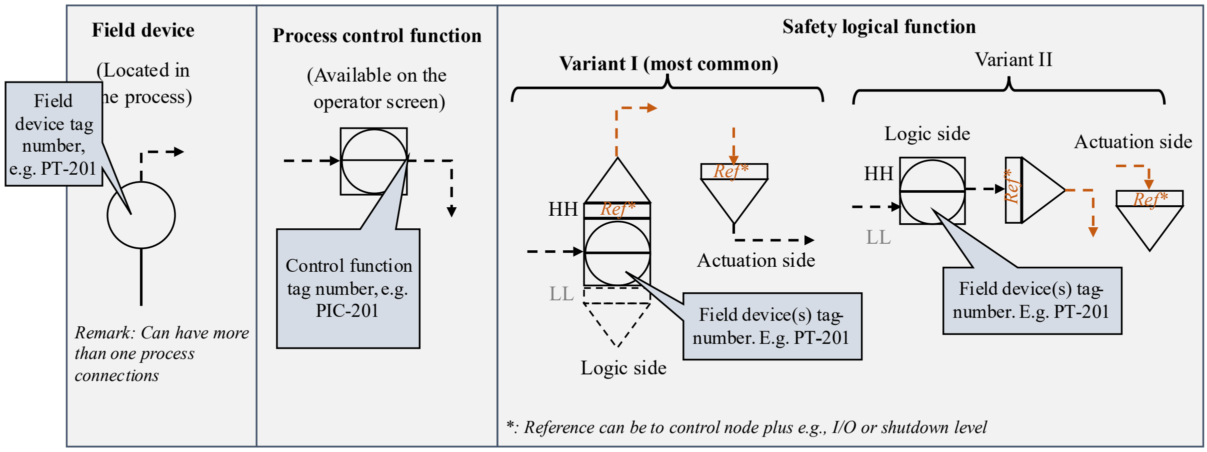



**Fig. 7. Graphical symbols for process sensors and controllers**

A selection of the most commonly used symbols on a P&ID is shown in Fig. 7 and explained as follows:

- Process sensor (or transmitter) mounted in the field (factory area): Open circle with line(s) (representing thin pipes that connect to the process equipment)
- Process control function: A circle with a horizontal stroke and a square around it. Signal lines from the process sensor(s) to the actuator are also included.
- Safety logic operation function: The logic symbol representing the safety controller is often split into two parts:
    - Logic side: Circle with a horizontal line, *plus* a triangle for each reference to the actuation side
    - Actuation side: Triangle with reference to the correct input side with connections to the device being actuated, e.g., a valve.

  Two variants are shown, with the left one perhaps the most applied.

The division into sides, logic, and actuation is used because the logic may receive inputs from one location and control one or more devices located elsewhere in the diagram. Representing these connections with direct signal lines often makes the diagram cluttered and difficult to read.

It may be noted that SCD, whose primary focus is detailing logical operations, uses different symbols for control and safety functions. Here, the logical operation is also split into a set of subfunctions, each realized using standardized function blocks.

A YouTube video about reading instrumentation symbols (focusing on process control) can be seen at https://youtu.be/3CYTe7AvRvM.

## 3.3.5 DCVs

A directional control valve (DCV) controls the direction of either pressurized air (pneumatics) or hydraulic fluids. The DCV consists of two main parts:

- Control side: Using either electrical, pneumatic, or manual actuation to move a slide connected to a movable stem inside the valve.
- Valve side: A chamber with holes (for entrance and exit flows, all referred to as ports) and a sliding stem and seals. The position of the stem determines which ports connect to each other, thereby directing the pressurized airflow.

Technical documents that detail DCV arrangements are called pneumatic control or circuit diagrams (for pneumatic DCV arrangements) or hydraulic control or circuit diagrams (for hydraulic DCV arrangements). The graphical symbols used on such drawings, both pneumatic and hydraulic, are explained in ISO 1219-1 (2012).

YouTube videos explaining the functioning of a pneumatic valve are:
- https://youtu.be/bXXL-0sf8gs
- https://www.youtube.com/watch?v=bXXL-0sf8gs

The signal that determines the position of the DCV can be:

- Electrical: Power is supplied to a coil (also called a solenoid) that sets up an electric field that can move the valve shaft so that the valve block changes position. The combination of an electrical signal block and a valve block is called a solenoid-operated valve.
- Pilot signal: A pneumatic or hydraulic signal routed via a pilot line from a preceding DCV.
- Manually: A manual push button or handle that, if pressed or released, causes the valve to change position.

Some DCVs use a combination of solenoid and pilot activation, in which the solenoid controls a pilot orifice that, in turn, operates the valve block. Such a valve is often just named a solenoid-operated pilot valve.

## 3.3.6 Pneumatic DCVs

While the graphical symbols for hydraulic and pneumatic DCVs are quite similar, they are often better explained separately due to nuances in their construction and connections. Here, we focus on the symbols used in pneumatic circuit diagrams. Fig. 8 identifies essential parts of a DCV symbol:

- The valve block with positions: Illustrated with one or more chambers (squares), where each chamber indicates the position of the valve. The connections to a chamber (or position) are called ports, and the arrows inside each chamber show how the ports connect internally and the direction of flow for that position.
- Actuation side with one or more actuation mechanisms: Illustrated with symbols for how the DCV is activated. Fig. 8 identifies two of these: Solenoid-operated and manual activation. Additional examples for actuation mechanisms are illustrated in Fig. 9.

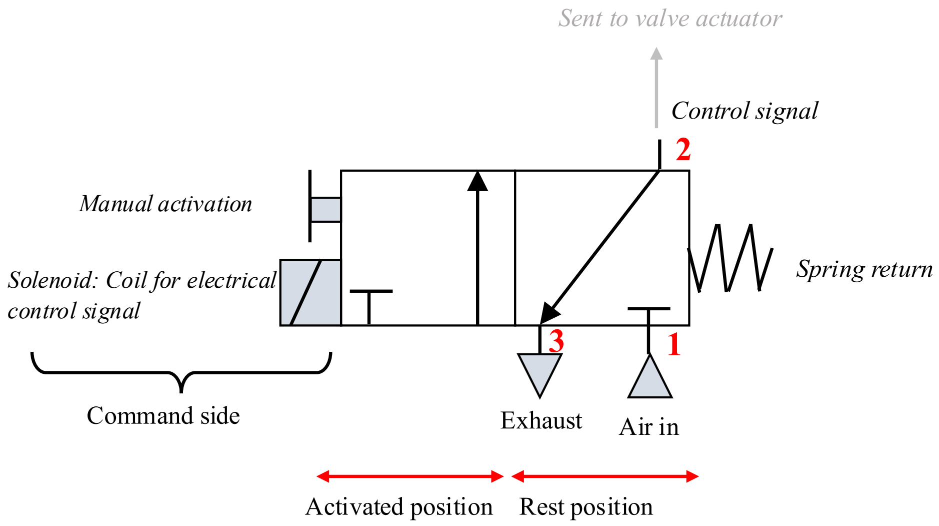



**Fig. 8. Solenoid and manually operated pneumatic valve of type 2/3**

From the figure, we can derive that:

- The valve has, besides the solenoid, also manual activation, meaning that the operator can press a push button to change the position, regardless of the status of the electrical signal.
- The valve block has three gates (connection points) that interconnect differently depending on the position.
    - (For a three-position valve, the rest position may be the middle chamber)
- The connection points (called ports) are:
    - Exhaust, i.e., the port that ventilates the pressurized air, and since it is air, it can be released directly to the environment.
    - Control signal, the port that connects to the tube entering the valve actuator
    - Air in/inlet, which is the connection point for the instrument air supply from the instrument air distribution systems.
- This valve has only two positions: Resting and activated.
    - The rest position is usually the rightmost chamber, where it is also shown how the ports connect to the air inlet, control signal, and exhaust.
    - The activated position is typically the leftmost chamber and closest to the activation symbol side. The position is interpreted by envisioning the left chamber replacing the right chamber while maintaining the external connections.
- The valve positions can be explained as follows:
    - In the rest position (right chamber), the pressurized air being returned from the valve actuator to port 2 is released to the environment through port 3 on the exhaust side.
    - In the activated position (left chamber), we "replace" (in our mind) the right chamber with the left chamber. One way is to move (in our visualization) the left chamber to the right side, allowing us to see how the connection points align.
    - We now see that the air inlet (port 1) is connected to the control signal side (port 2), indicating that the pressure signal is applied to the valve actuator.
- The compressed spring (on the right side) will assist the valve in moving back or maintaining the rest position when the solenoid receives no signal or when no manual activation has been performed.

The naming of pneumatic DCVs includes the number of ports and positions in the format of <number of ports>/<number of positions>. For example, the valve in Fig. 8, which has three gates and two positions, is called a 3/2 valve.

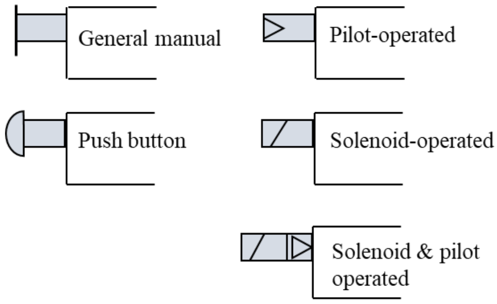



**Fig. 9. Selected symbols for pneumatic control valve activation**

The way the positions change inside the valve block is illustrated in Fig. 10. The valve block has a chamber, three holes (ports), and a stem that connects to the solenoid's coil. The stem has some seals (three of them) that ensure no leakage from one side to the other. The coil will generate a magnetic field that can move the valve from its rest position to its activated position. The upper illustration is assumed to be the rest position, where the spring has driven the stem back to a position that allows air to flow from 1 to 2, with 1 being the exhaust port and 2 being the port connecting to what the valve controls. When the coil is energized, the stem moves, compressing the spring and allowing air to flow between ports 2 and 3, with port 3 supplied with air pressure.

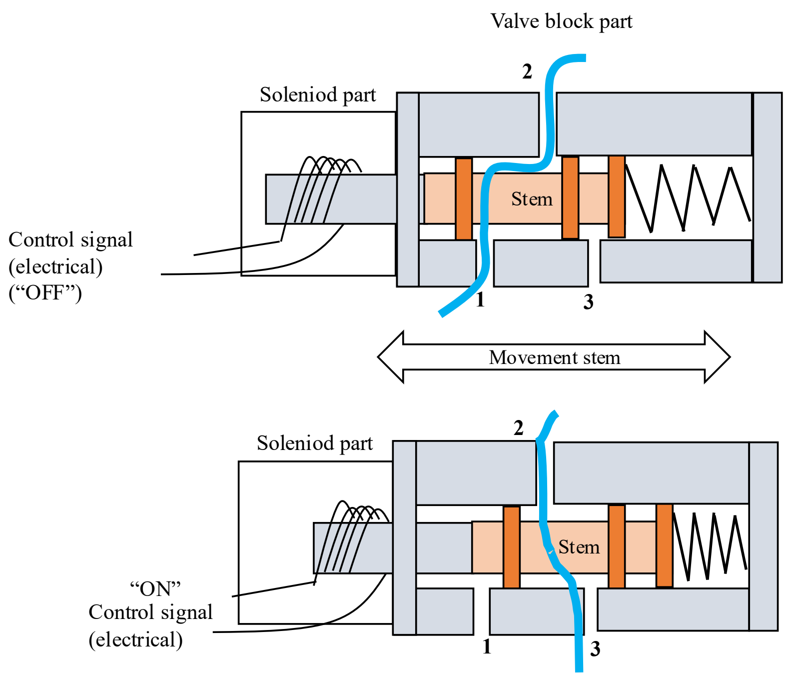



**Fig. 10. How the valve block is built to change positions**

A more complex DCV is a 5/3 solenoid-operated DCV shown in Fig. 11, with 5 ports and 3 positions. Having three positions means the DCV symbol has three chambers, each with 5 ports through which compressed air enters or exits.

The three positions are:

- Rest (inactivated): In this case, the slide the port, and no control signal is provided.
- Move direction 1 (left chamber): This position is activated when solenoid on the left side is energized. Pressurized air (from port 1) now connects to the control signal (output) at port 2. In contrast, the control signal at port 4 connects to the exhaust side (port 3). The valve returns to its rest position when the solenoid is no longer energized.
- Move direction 2 (right chamber): This position is activated when the solenoid on the right side is energized. Now, the control signal outlet at port 2 connects to the exhaust at port 5, while the

air supply connects to the control signal at port 4. The valve returns to its rest position when the solenoid is no longer energized.

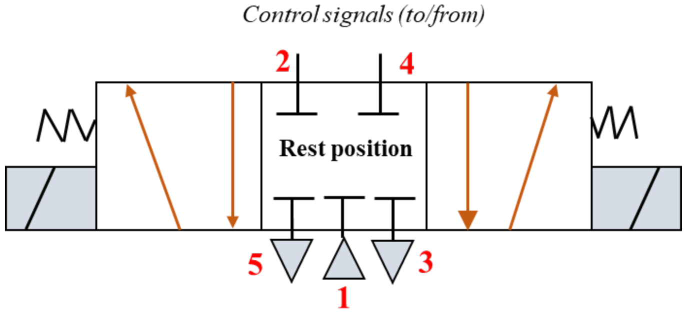



**Fig. 11. Solenoid-operated pneumatic valve of type 5/3**

There are many additional port and position combinations, but 3/2 and 5/3 seem most common, even though the ports can be connected in different ways. The two valve examples identified the difference between bistable and monostable valves:

- Monostable, meaning that the valve is activated from one side only, which was the case for the 3/2 valve in Fig. 8. A 3/2 can also be designed as bistable.
- Bistable, meaning that the valve is activated from both sides, which was the case for the 5/3 valve in Fig. 11. Also, 5/3 valves can be monostable.

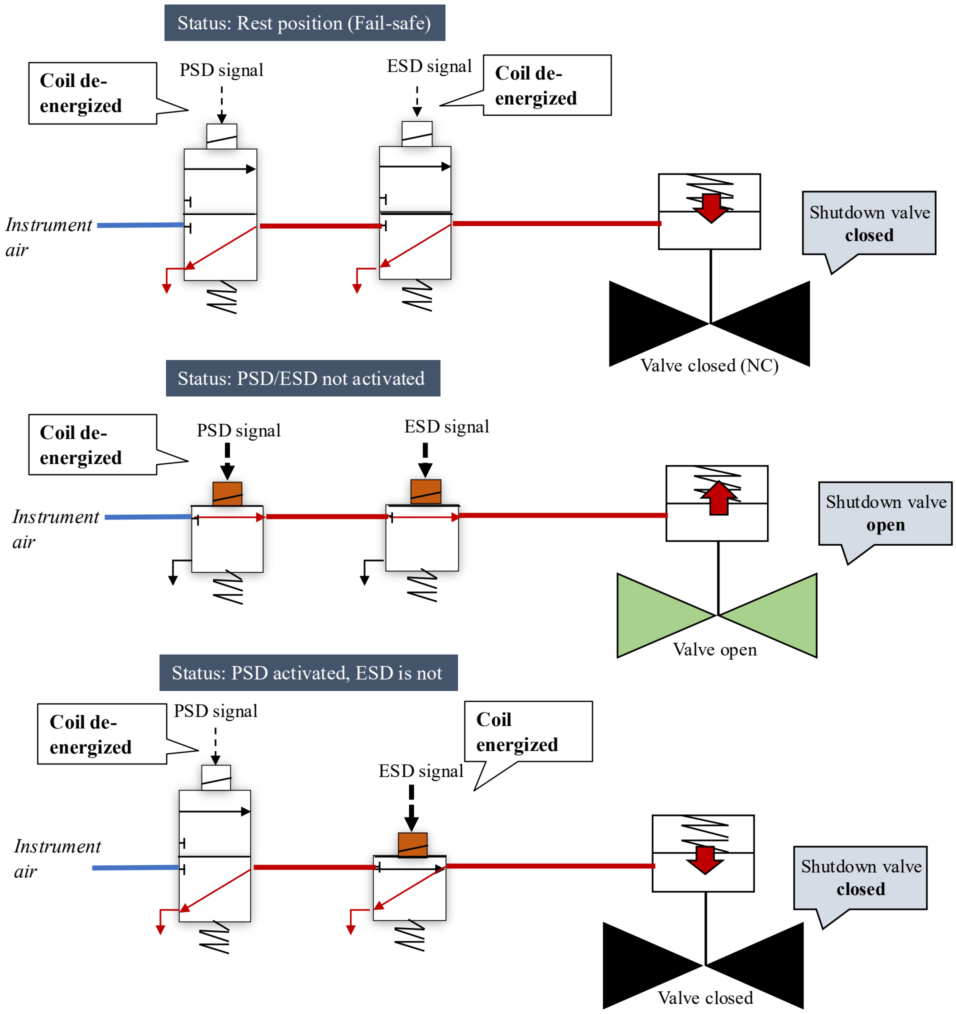



**Fig. 12. Activating a safety shutdown valve**

Fig. 12 illustrates how pneumatic (solenoid-operated) valves can realize logical operations to control the position of a shutdown (S/D) valve. One solenoid receives a signal from the process shutdown system (PSD), and the other solenoid valve receives a command (on/off signal) from the emergency shutdown system (ESD). The state of the solenoid valves determines whether S/D opens or closes:

- Rest position (top): ESD or PSD. The coils are not activated, either due to simultaneous activation of ESD and PSD or to a power loss affecting both DCVs. The shutdown valve enters the fail-safe position.
- No emergency: The PSD and the ESD apply a constant control signal that keeps the coils energized, causing the shutdown valve to stay open.
- Hazardous event leading to a PSD activation: The activation of the PSD is by removing the control signal, so that the PSD DCV changes position, causing the shutdown valve to close

Note that the shutdown valve would also close if the ESD is activated (removing the control signal), rather than the PSD. Activation of both ESD and PSD results in the same configuration as shown for the rest position.

### 3.3.7 Hydraulic DCVs

Hydraulic control valves have similar functionality to pneumatic control valves, but the medium flowing through the valve is pressurized hydraulic fluid rather than compressed air. The operating pressure for hydraulic control valves is often much higher than for instrument air, often 10-100 times higher. Hydraulic fluids are also less compressible, meaning faster and more accurate activation of equipment operated by the valves. The hydraulic control valves are sometimes referred to as directional control valves (DCVs), as they control the direction of flow.

| | |
|---|---|
| | YouTube video showing how hydraulic valves work.<br>See https://youtu.be/hkyCJpN-1O4 |

Hydraulic control valves have ports like pneumatic control valves do. However, there are two main differences:

- The exhaust port cannot release fluids into the environment, as the fluids will pollute and are flammable.
- There are two ports for the control (often as an on/off) signal, not one port only. The pressurized hydraulic control signal sent to operate, e.g., a shutdown valve, requires a return path, as the circuit for hydraulic fluids with supply, control, and return (exhaust) must be in a closed-loop system.

The hydraulic control valves have the following ports:

- P-port, which is connected to a pipe coming from the hydraulic pump or accumulator that provides pressurized hydraulic fluids
- The T-port is connected to the pipe leading to the tank, meaning the reservoir of hydraulic fluid, from where the hydraulic fluid is filtered and pressurized again. The pump and tank system is a closed-loop system to avoid any fluids entering the environment.
- Control ports A and B connect to the operating device (like an on/off valve). One port (often port A) is connected to the pressurized side of the valve actuator, and the other (port B) is connected to the return side.

The positions of the valves with chambers, arrows, and connection points can be interpreted in the same way as for pneumatic valves. Fig. 13 This section presents examples of graphical symbols for hydraulic control valves with two or three positions. The valves are named similarly to pneumatic valves, based on the number of ports and positions.

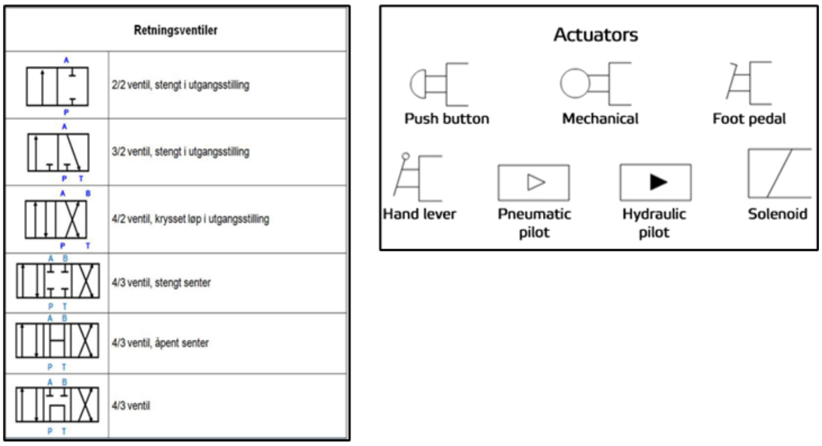



**Fig. 13. Graphical symbols for hydraulic valves**

Fig. 14 shows how the positions of a 4/3 hydraulic valve are operated by looking inside a valve block. We assume that this is a bistable valve, operated from both sides:

- Activated from the left side (left chamber): Pressurized fluids are provided at the P port and routed directly to the A-port. The B-port, which is connected to the return side of the controlled equipment, is directly connected to the tank.
- Center position (middle chamber): In this position, the A and B ports are disconnected from the P and T ports. Therefore, the fluids in pipes to/from the connected equipment are locked in, and the valve actuator cannot move.
- Activated from the right side (right chamber): In this position, the A port connects to the T port, and the B port connects to the pump side, causing the valve to operate in the opposite position, which we assume is the rest (safe) position. For a valve to be fail-safe, it should be able to switch even if the pump fails to provide hydraulic pressure. For this purpose, we need a spring that is compressed when the valve is actuated and released when no activation.

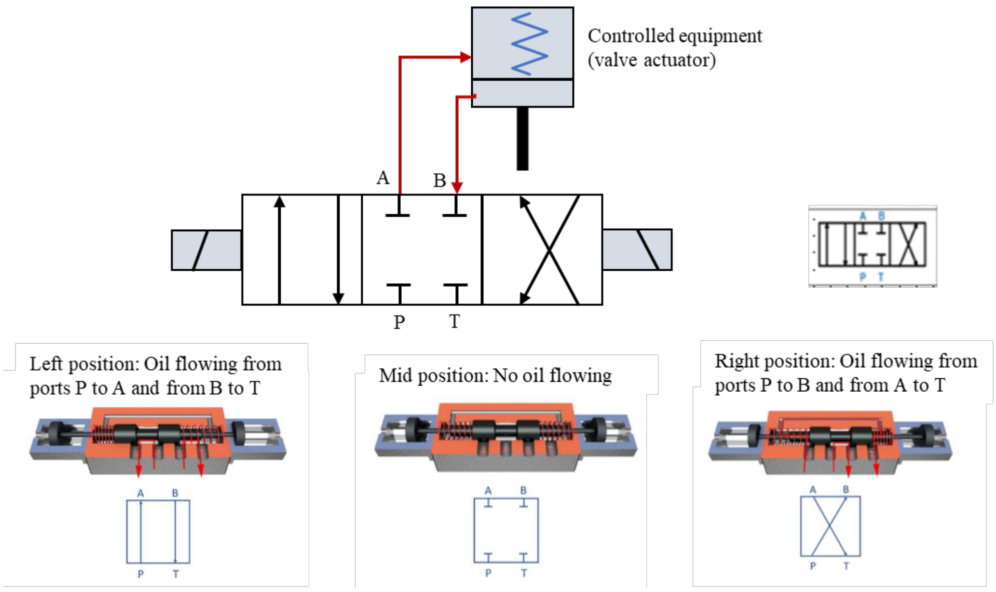



**Fig. 14. Explaining a 4/3 control valve**

The 4/3 valve can be implemented in other ways than shown in Fig. 14, depending on how the valve block is internally constructed.

### 3.3.8 Comparison of DCV symbols (against P&ID)

Fig. 15 identifies how the DCV symbols are applied in a circuit diagram and a P&ID with reference to where the systems may be found on the valve, identified with numbers.

It may be noted that solenoid-operated valves may also be located in cabinets near the valve, rather than being directly mounted as shown in the figure.

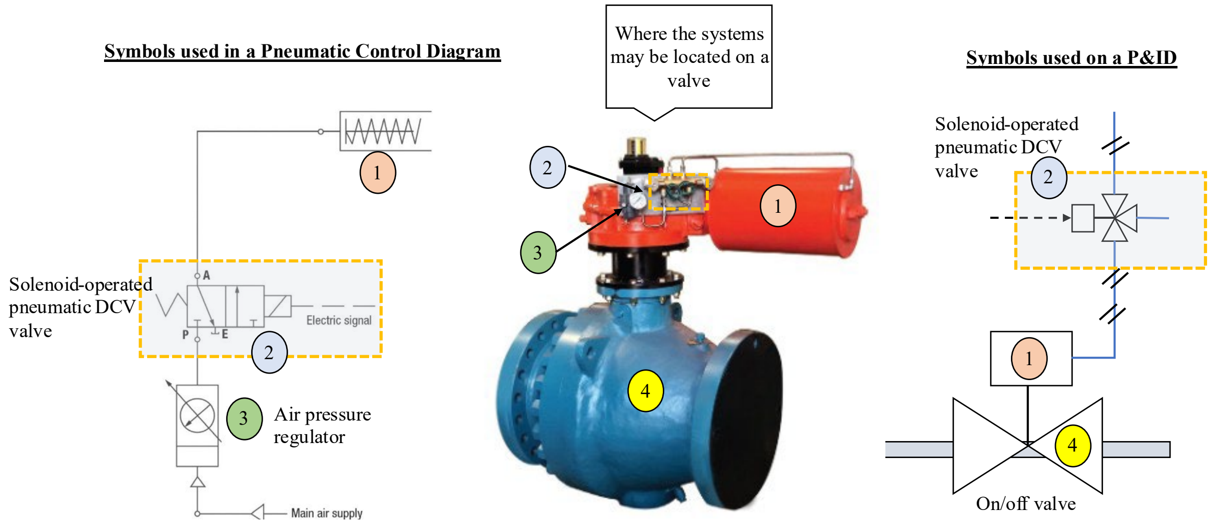



**Fig. 15. Electrically operated pneumatic valves adapted from Welch (2020)**

## 3.4 Tagnumbers

Process equipment and field instruments are labeled with a unique code, referred to as a tag number, that indicates the equipment's function and location. All equipment is fitted with a nameplate showing the tag number, and the tag number is also added to all documentation that illustrates or mentions the equipment, as well as to the maintenance (management) system. A tag number is not the same as the manufacturer's serial number or product model number; this information is stored elsewhere (such as in the maintenance management system). This means that the tag number remains the same even if the equipment is replaced by a new one.

### 3.4.1 Tag number

The tag number consists of digits and letters that identify the equipment's function, system affiliation (where it belongs), and its location. A widely adopted format for the letter symbols is in the international standard ANSI/ISA-5.1 (2024). Coding of location and system affiliation may follow the company or national guidelines, such as NORSOK Z-DP-002 (1996) and illustrated in Fig. 16.

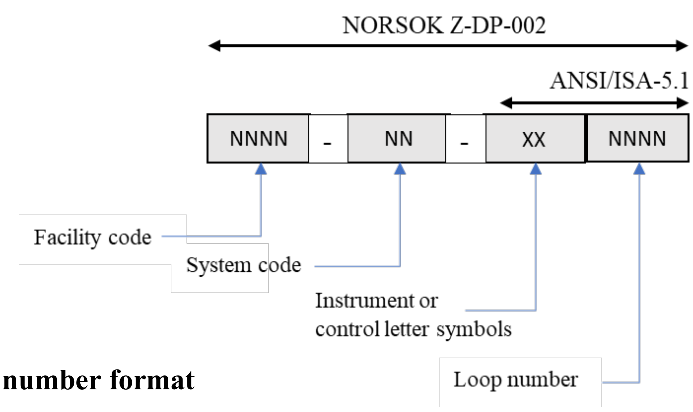



**Fig. 16. Tag number format**

The information can be explained as follows:

- The facility code is usually a series of digits that refers to a specific plant/facility.

- System code, usually digits, refers to a specific system within the plant.
- The equipment code, as letters, identifies the equipment function, for example, pressure transmitter, level transmitter, level control, fire detector.
- The loop or sequence number (digits) identifies a specific instrument loop. Equipment with the same loop number has some interaction. If there are redundant loops (i.e., loops with equipment performing the same function), a letter may be added. E.g., A for one loop and B for the other. If redundant loops are given different loop numbers, it would not be so straightforward to understand that they are related.

**Example 1:** 1105-27-PT-0002
Equipment is installed with system 27, located at facility code 1105. The equipment is a pressure transmitter (PT) with loop number 002.

**Example 2:** 1105-27-PT-0010A & 1105-27-PT-0010B
At the same facility and system (27), there are two redundant pressure transmitters (PT) (A and B) with loop number 0010.

**Example 2:** 1128-13-PCV-1301
At another facility, a pressure control valve (PCV) is installed in system 13, loop 13001.

Also, control functions, even if not physical assets, are assigned tag numbers, as they are on P&IDs and in SCD drawings.

### 3.4.2 Syntax for equipment codes (applied with tag numbers)

In the examples above, we introduced some letter codes for equipment, such as PT and PCV. The syntax used for equipment coding is often based on international standards, but companies themselves introduce some variants. One widely recognized standard for instrumentation symbols and identification is ANSI/ISA-5.1 (2024), even if some variants may exist. According to this standard, the coding for input devices and controllers consists of 2-3 letters, where each letter serves a purpose described in Tab. 1.

**Tab. 1. Format for equipment code (letters)**

| Type of device | First letter | Middle letter (if included) | Last letter |
|---|---|---|---|
| Input devices | The physical parameter (pressure, flow, level, etc.) measured by the instrument or used for control | Whether the measurement is presented on an operator screen | The output of the function (transmitter, alarm) |
| Actuated devices | Many variants, and less standardized. Here are some examples:<br><br>Option 1: The physical parameter measured by the input device determines the position or state of the actuating device.<br><br>Option 2: Use an "unclassified" letter, such as X, whose meaning is defined in the drawing. X may be defined as an on/off type of actuation. | Identifies the extent to which the device is part of a control function with letter "C" (as opposed to an on/off function, where the middle letter is not included) | The type of actuating device, e.g., a V for a valve, a Y for a relay, and a Z for a position indicator mounted on a valve. |

The syntax for equipment coding, i.e., the meaning of each of the letters in its position, is shown in Tab. 2.

**Tab. 2. Syntax for equipment coding (selection of coding from ISA/ANSI 5.1)**

| Letter | As the first letter (Measured /type of input) | As the middle letter (Supplementary, Optional) | As the last letter (output action) |
|---|---|---|---|
| **A** | Analysis | Alarm | |
| **C** | | Control | |
| **E** | Voltage (electric) | | |
| **F** | Flow | | |
| **G** | | Glass/viewing device | |
| **H** | Hand | | High |
| **I** | Current | Indicator | |
| **L** | Level | | Low |
| **P** | Pressure | | |
| **S** | Speed | Switch (for alarm/trip) | Switch (field instrument) or stop (logic) |
| **T** | Temperature | | Transmitter |
| **V** | Vibration | | Valve |
| **X** | Unclassified. In Norway, often used when input is safety on/off | Unclassified | |
| **Y** | | | Convert/compute/ Relay/solenoid valve |
| **Z** | Position | | |

This YouTube video explains more about instrumentation symbols and letter coding.

Fig. 17 gives a simple example for how the letter codes and loop numbers are applied, excluding facility numbers and system numbers:

- Left side: The level transmitter (LT) measures the level in the tank and sends the signal to the level controller (LIC), which provides a control signal to the level valve (LCV).
- Right Side: The flow transmitter (FT) measures the flow in the pipeline and sends a signal to a flow controller, which sends a signal to the flow valve (FCV).

It should be noted that the controller symbol does not imply only a PID controller; rather, it denotes any function implemented in a process control system, such as PID, stop, start, or similar.

A loop number (and sometimes also a system number) is added to make all devices within the control loop unique. Fig. 17 illustrates two approaches to loop numbering: on the left, the loop number increases by 1 for each piece of loop equipment, starting with the input device. On the right side, which is the most used approach, the equipment of the same loop has the same loop number.

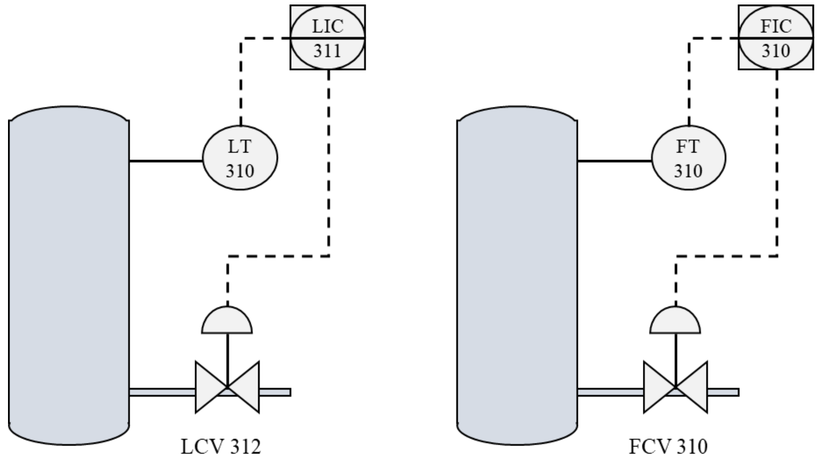



**Fig. 17. Numbering of instrument loops**

### 3.4.3 Sector-specific letter syntax

The letter syntax for safety (open/close) valves is less standardized, and numerous alternatives are used in industry, such as:

- EV – Emergency (shutdown) valve
- XV – Process shutdown valve (PSD)
- DHSV -downhole safety valve (a valve mounted 500 meters below the valve tree of an oil or gas well)
- SCSSV – surface-controlled subsurface safety valve (An alternative name used for DHSV)
- SSIV – sub-surface isolation valve (a safety valve installed subsea in a pipeline within the 500-meter zone of an offshore facility)
- PMV – Production master valve (a safety valve installed in the well tree)
- PWV – Production wing valve (a safety valve installed in the well tree)
- XOV – Crossover valve (a safety valve installed in the well tree)
- AMV – Annulus master valve (a safety valve installed in pipes that enter the annulus part of an oil or gas well)

For simplicity, we adopt only XV or EV.

Solenoid and pilot-operated pneumatic or hydraulic valves often use the following letters:

- XY (for valves operating PSD valves)
- EY (for valves operating ESD valves)

For simplicity, both can be used.

Syntax tables like the one in Tab. 2 does not cover fire and gas detection field devices. However, the following letter symbols are often applied:

- GD – Gas detector
- FD – Fire or flame detector
- SD – Smoke detector

## 3.5 Technical documentation

This section explains the technical documents within the scope of this chapter, starting with the process flow diagram (PFD), which is among the first technical documents prepared for a new process plant.

### 3.5.1 Process flow diagram - PFD

A Process flow diagram (PFD) is a drawing prepared by process engineers as one of the first documents describing a planned process facility. PFD should not be confused with the same abbreviation for "Probability of failure on demand" in Chapters 8 and 9.

The PFD may exist as a single sheet (page) or be distributed across several sheets. Fig. 18 is an example of a PFD, and based on this version, we explain some of the drawing's key attributes:

- The drawing includes larger process equipment and the main connecting pipes.
- Key information about the dimensioning of the equipment is added (on the top) in square boxes.
- Some high-level information is provided about the control functions
- Arrows/connections (left and right sides of the drawing) showing how a particular PFD sheet is connected to other PFD sheets.

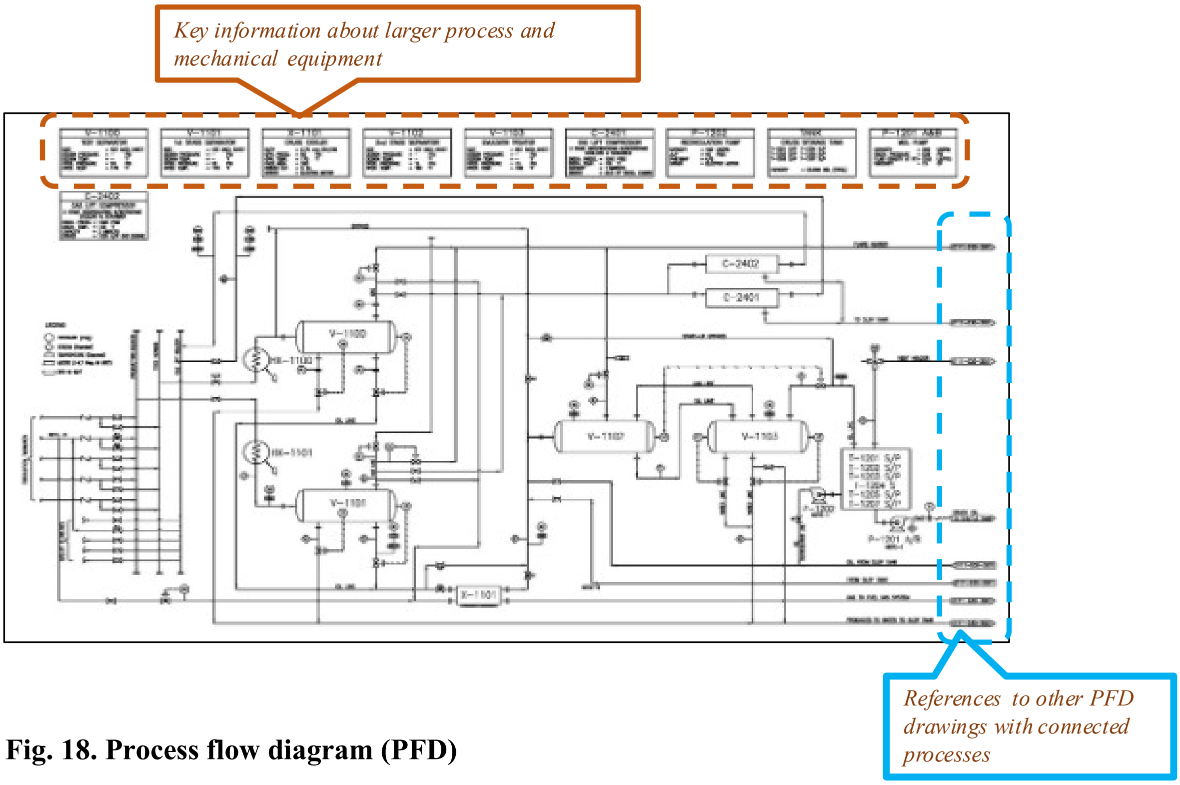



**Fig. 18. Process flow diagram (PFD)**

The PFD is also the starting point for developing P&ID drawings.

### 3.5.2 Piping & instrument diagram (P&ID)

The piping and instrument diagram (P&ID) details the process systems at a facility with the following information:

- All process equipment (tanks of various kinds)
- All mechanical equipment (valves, pumps, compressors)
- Pipelines and connected pipes and tubes, including dimensions
- Sensors and other instruments, and how they connect to process equipment and pipes

P&IDs are often considered the most essential technical document for a process plant, as they are relevant for most engineering disciplines, including process, mechanical, automation, electrical, and technical safety. It is a common document for the disciplines to coordinate decisions, purchases, and further design and development during the engineering phase. In operation, engineers, technicians, and operators consult the document almost daily for operations, maintenance, testing, and modifications, perhaps not always directly but via its representations on operator screens.

The most commonly referenced standards with rules for how P&IDs are drawn are:

- ISO 15519-1 (2010): General rules
- ISO 15519-2 (2015): Measurement and control
- ANSI/ISA-5.1 (2024): Instrument and control symbols

The overall layout of a P&ID diagram is shown in Fig. 19. The left and right sides identify how pipes and control signals connect to other diagrams. The middle section contains the piping and instrumentation details associated with the process equipment of a process section. The lower part of the document contains the document number, revision status, and approval.

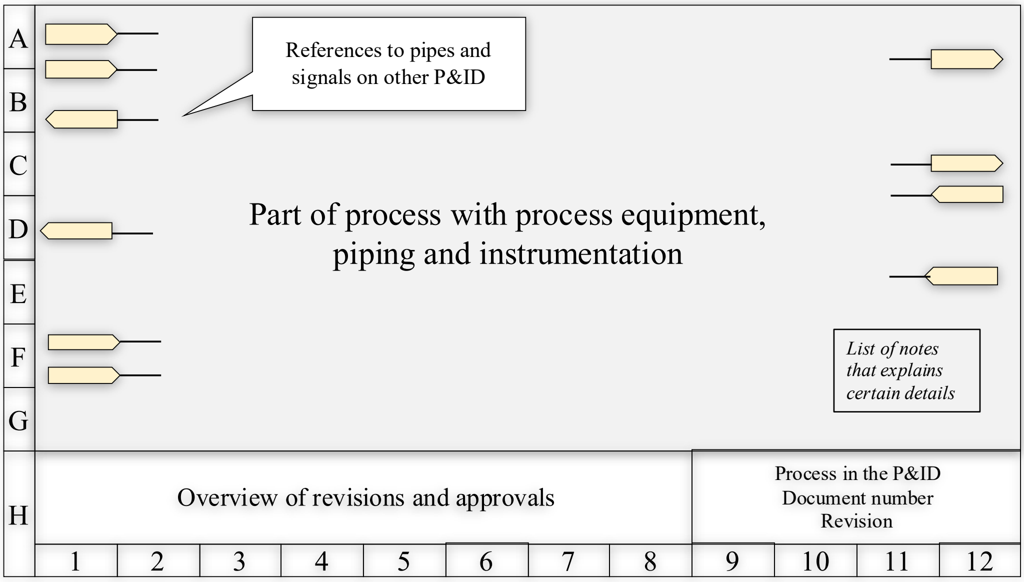



**Fig. 19. General P&ID layout**

In this course, we simplify the way P&IDs are drawn by focusing on the control and safety functions, and excluding piping details, leaving a simplified P&ID in the format as shown in Fig. 20

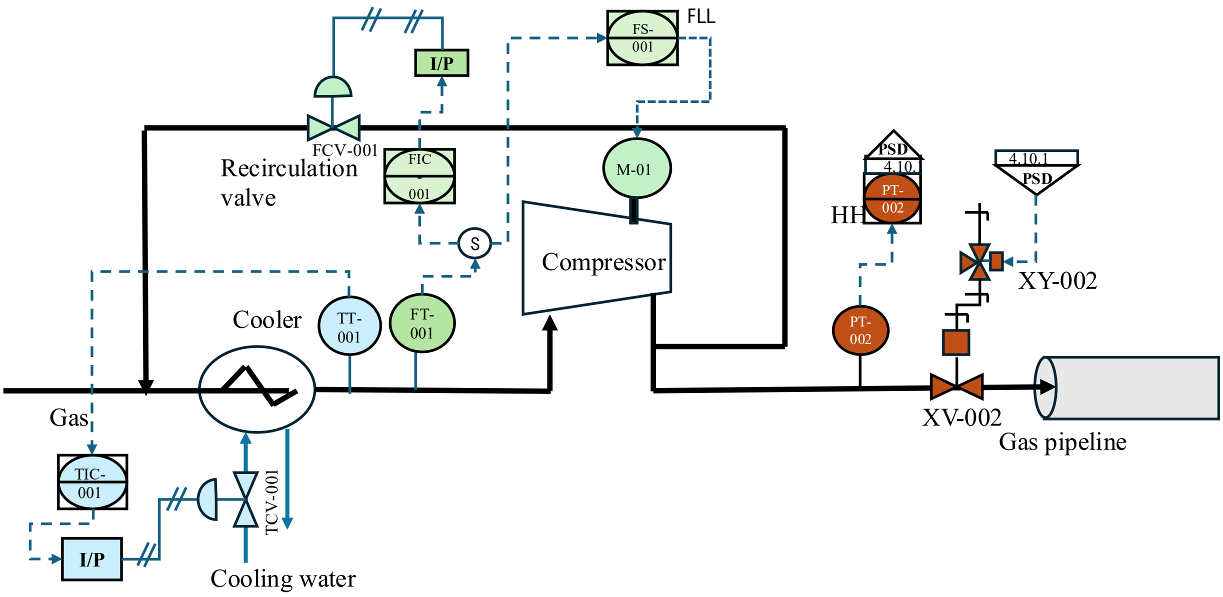



**Fig. 20. Examples of a simplified P&ID diagram**

From this P&ID we can learn the following:

- The temperature of the gas entering the compressor is controlled by a cooling unit. The electrical signal from the temperature transmitter TT-001 is sent to the process controller TIC-001, which outputs an analog current (I) signal for the desired position of the pneumatic control valve TCV-001 in the cooling circuit via a current-to-pressure (I/P) signal converter.
- The compressor flow is regulated to ensure operation within its designated performance envelope. Flow transmitter FT-001 measures the gas flow rate, and flow controller FIC-001 adjusts the recirculation valve position to maintain the required flow through the compressor.
- The flow transmitter signal is also sent to the control system for an on/off function (FS-001). If the flow is too low (FLL), it sends a stop signal to the motor controlling the compressor speed.

- The pipeline has a design limit for how much pressure it tolerates before rupturing. As pipe rupture is a safety-critical event, the corresponding function to prevent it is a safety function. The safety function consists of:
  - Pressure transmitter PT-002 monitors the pressure, and if the pressure becomes too high, a hydraulically operated shutdown valve shall close.
  - The safety controller reads the measurement from the transmitter and triggers an action if the measured value exceeds the setpoint, here marked as high-high (HH).
  - The closing of shutdown valve XV-002 is made in two steps:
    - First, to send a closure signal (often by the safety controller shutting off the power signal (on/off) to the solenoid-operated hydraulic DCV, causing this DCV to change position
    - Second, the hydraulically operated shutdown valve XV-002 is losing hydraulic pressure due to the change in DCV position. Its spring-assisted fail-safe close design means that it enters the closed position.

Examples of how detailed P&IDs may identify piping details are shown in Fig. 21. Examples include piping sizes, coding for pipeline types, the locations where the pipeline changes from one size to another (yellow), and the locations of manual valves.

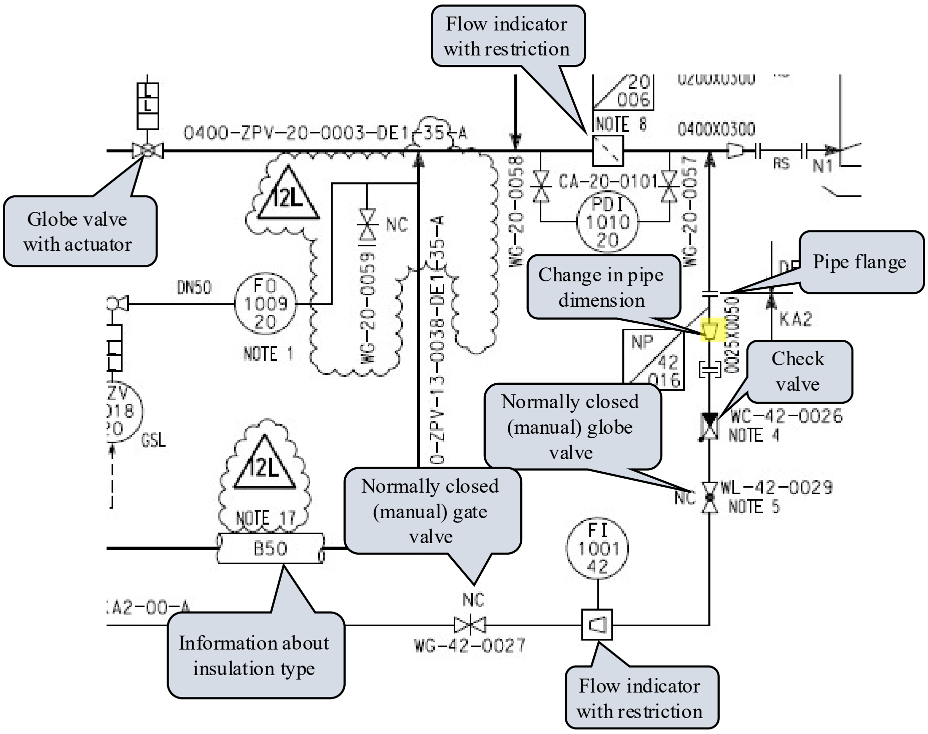



**Fig. 21. Examples of details in a P&ID**

A YouTube video about reading P&ID diagrams

## 3.5.3 System control diagram (SCD)

A System Control Diagram (SCD) is a technical drawing for PLC and DCS logic representation following a technical specification IEC PAS 63131 (2017). The guideline includes rules, standardized graphical symbols, and functional specifications for commonly used function blocks in control and safety functions.

Many of the larger PLC and DCS vendors provide their own "SCD library" of these functions, meaning that the logic is implemented according to the SCD notations. If the SCD is drawn using a tool that can export to XML or AML, vendors can import these files into their application program editor as a starting point for more detailed configuration.

A web page [https://scd-diagram.no/](https://scd-diagram.no/) provides more information about SCDs, including drawing tool to integrate with Microsoft Visio.

#### 3.5.3.1 Examples of SCD standard function blocks and drawing legends

Fig. 22 shows how a function block and related information are illustrated in an SCD. Key information includes the function block name, the node name where the block is implemented, and the device tag number or identifier.

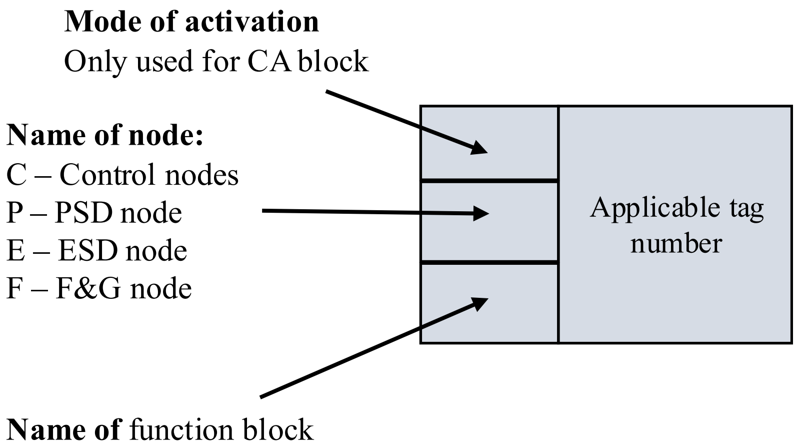



**Fig. 22. SCD function block symbol**

IEC PAS 63131 (2017) identifies several standardized functions for control and safety functions, some of which are:

| Short Name | Full Name | Purpose |
|---|---|---|
| MA | Monitoring of Analog Process Variables | Monitors process conditions such as pressure, temperature, flow, and level. |
| LB | Safeguarding Shutdown Level | Evaluates abnormal conditions and initiates shutdown actions when required. |
| CA | PID Controller (Continuous Analog Control) | Calculates the required control action for continuous regulation. |
| OA | Analogue Output | Transmits analog control signals to modulating field devices. |
| SBE | Control of Electrical Equipment | Controls electrical equipment, including pumps, motors, fans, and heaters. |
| SBV | Control of Pneumatic/Hydraulic Equipment | Controls pneumatic and hydraulic final elements such as on/off valves and dampers. |
| HA | Analogue Input Command | Provides a manually entered binary (on/off) command from the operator or control logic, typically used for enabling, disabling, starting, stopping, or selecting functions |

| | | |
|---|---|---|
| HB | Binary Input Command | Provides a manually entered binary (on/off) command from the operator or control logic, typically used to enable, disable, start, stop, or select functions. |

Using MA block in Fig. 24 as an example, IEC PAS 61131 explains inputs as well as outputs for each function block. To fully understand the meaning of these parameters, it is necessary to consult the IEC document.

| Inputs | MA | | Outputs |
|---|---|---|---|
| Normal function input | X | Y | Normal function output |
| External fault | XF | YF | Function failed |
| Force blocking alarm HH | FBHH | AHH | Action alarm HH |
| Force blocking alarm LL | FBLL | BHH | Status alarm HH |
| Force suppression alarm HH | FUHH | WH | Warning alarm H2) |
| Force suppression alarm WH | FUWH | WL | Warning alarm L2) |
| Force suppression alarm WL | FUWL | ALL | Action alarm LL |
| Force suppression alarm LL | FULL | BLL | Status alarm LL |
| | | BBHH | Action alarm HH is blocked |
| | | BBLL | Action alarm LL is blocked |
| | | BU | Status suppressed |
| | | BB | Status blocked |
| | | BXHH | Status event HH |
| | | BXH | Status event H |
| | | BXL | Status event L |
| | | BXLL | Status event LL |
| Operator station: | | | Operator station: |
| Blocking HH on/off | | | Alarms and faults |
| Blocking LL on/off | | | Alarm and event limits |
| Suppression on/off | | | Blocked |
| | | | Suppressed |

**Fig. 23. Inputs and outputs for MA block**

### 3.5.3.2 MA block

The MA function is used to acquire, scale, and monitor analog process measurements such as pressure, temperature, flow, or level. The function compares the measured value against configured alarm and event limits and generates warning and action alarms when predefined thresholds are exceeded.

In addition to monitoring the process value itself, the MA function can detect instrument faults and support alarm suppression and blocking. Consequently, the MA template acts as the primary interface between process measurements and the control and safeguarding logic, providing both operator information and alarm signals for downstream functions.

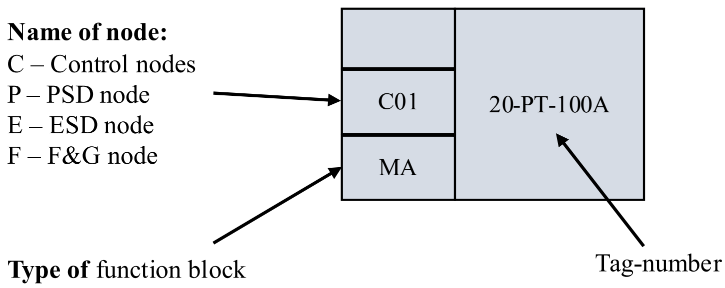



**Fig. 24. MA block**

#### 3.5.3.3 CA block

The CA function implements continuous process control using a PID algorithm. It receives a measured process variable and compares it with a setpoint to calculate a control output for the final control element, such as a control valve, variable-speed drive, or heater.

The template supports automatic and manual operation, internal and external setpoints, tracking, feed-forward control, safeguarding actions, alarm handling, suppression, and blocking. Its purpose is to maintain the controlled process variable at the desired operating point despite process disturbances.

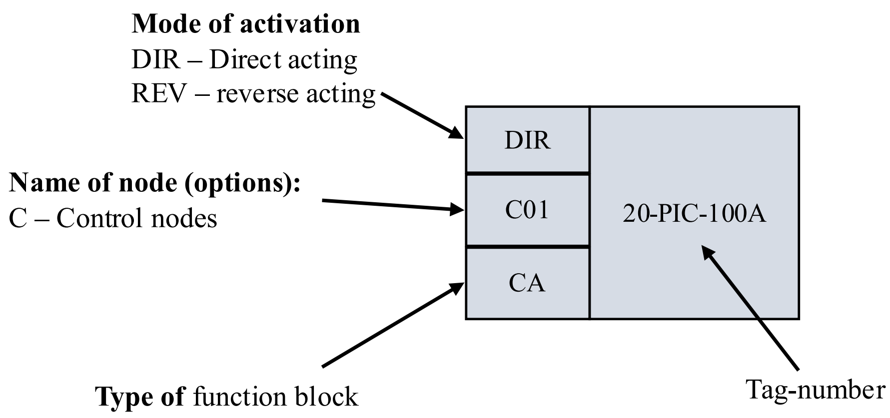



**Fig. 25. CA block**

Only the CA symbol indicates that it is possible choose "mode of activation", as either:

- DIR: Increased input compared to the setpoint shall cause increased output
- REV: Increased input compared to the setpoint shall cause decreased output

#### 3.5.3.4 LB block

The LB function is used for implementing the shutdown level within the control and safety system. The standard explicitly describes it as a shutdown level that collects signals from a group of initiators and distributes shutdown commands to a group of action elements. The function, therefore, acts as a common shutdown aggregation point for multiple inputs and outputs, with outputs determined by logical operations configured into the function (e.g., voting). The function can latch shutdown signals, meaning the shutdown state remains until a reset is performed. The LB function often issues commands to final elements via SBE and SBV blocks and receives inputs from MA and HB blocks, as well as from stand-alone arithmetical and logical functions. The LB block may also connect to an OA block in a PID function to force a control valve to close, regardless of the control signal provided from the CA block.

The function block is applicable to PSD, ESD, and PSD nodes, but can also be used with the CA block for unit shutdowns. While most SCD blocks identify related tag numbers, the LB block references a shutdown-level identification.

- For PSD, the reference may be PSD plus the number format identifying the specific shutdown level, and similarly for ESD and PSD. For example, PSD 4.1.15; however, the formats will vary widely depending on company preferences.
- LB applied for control nodes reference a unit shutdown level. For example, USD 5.2.21. As already noted, the companies may use their own coding for this purpose.
- On a specific SCD drawing, it is not common to show all inputs and outputs to the LB block, but only those relevant to the functions that are shown on the specific drawing.

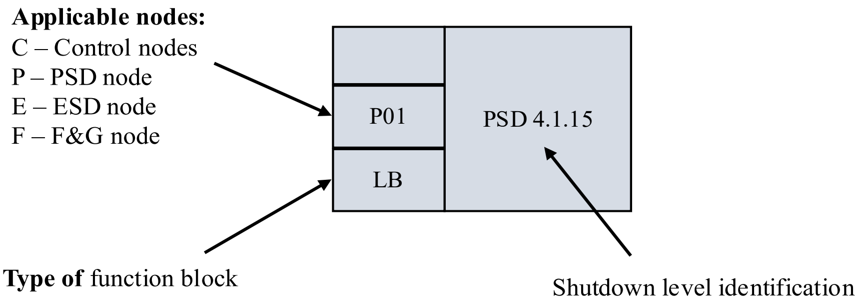



**Fig. 26. LB block**

### 3.5.3.5 SBV block

The SBV function provides binary control of pneumatically or hydraulically actuated on/off valves. The function can be implemented in control, PSD, and ESD nodes. The function receives open and close commands from operators or control logic and generates corresponding actuator outputs.

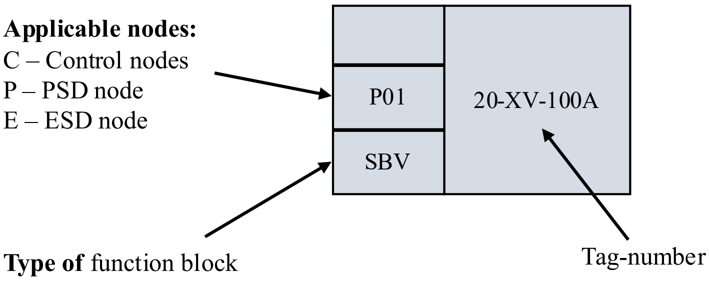



**Fig. 27. SBV block**

It monitors valve position feedback, confirms successful movement, detects failures, and supports safeguarding actions that force the valve into a predefined safe state. The template also includes blocking, suppression, and outside-operation modes, making it suitable for integrating process valves into both control and shutdown systems

### 3.5.3.6 SBE block

The SBE (Control of Electrical Equipment) function is used to control and supervise electrically powered equipment such as pumps, motors, fans, compressors, and heaters. It is relevant for control, as well as ESD, PSD, and F&G nodes.

It receives commands from operators or control logic and translates these into start and stop actions while monitoring equipment status, availability, and feedback signals. The template incorporates operating modes, interlocks, fault handling, alarm generation, and safeguarding functions, allowing abnormal conditions or shutdown requests to automatically take the equipment to a predefined safe state. As such, the SBE function represents a complete lifecycle model of an electrical actuator, combining control and supervision within a single standardized function block.

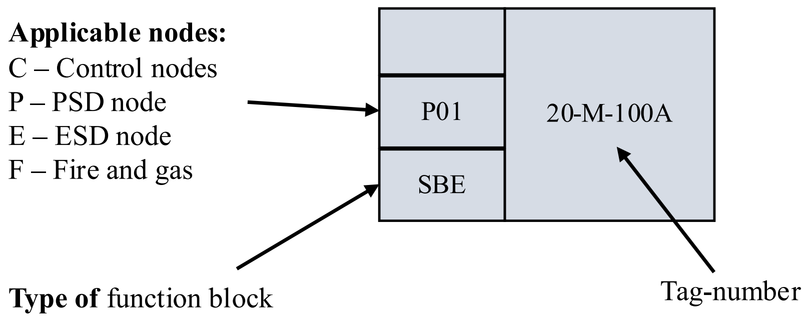



**Fig. 28. SBE block**

The SBE template therefore serves as the standard control interface between the automation system and electrical equipment connected through motor control centers (MCCs) or equivalent electrical systems.

### 3.5.3.7 OA block

The OA function provides an analog output signal from the control system to a field device. It is typically used to drive equipment that requires a continuously varying control signal, such as control valves, variable-speed drives, heaters, or dampers, and is most relevant to control nodes. The function handles signal scaling, output limiting, feedback monitoring, fault handling, some safeguarding actions, blocking, and suppression.

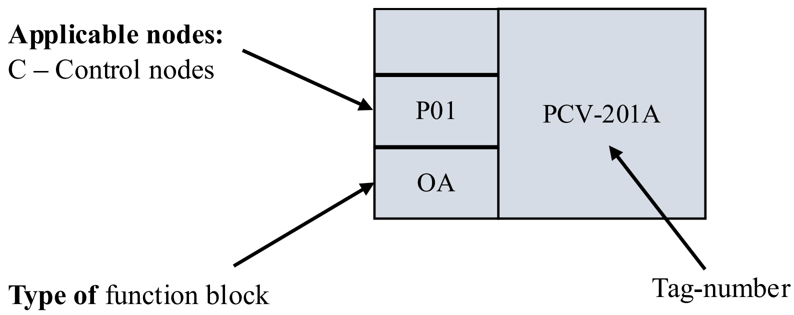



**Fig. 29. OA block**

The OA block is sometimes added after the CA block. Unlike the CA template, which calculates the required control action through a control algorithm, the OA template is responsible for transmitting and supervising the actual signal sent to the field device. The OA function, therefore, represents the interface between the control system and modulating actuators. In contrast, the SBE and SBV templates are used for binary actuation of electrical equipment and on/off valves, respectively. This distinction allows the SCD framework to represent both continuous and discrete actuation using standardized function templates.

### 3.5.3.8 Arithmetical and logical functions

SCD diagrams can link function blocks via arithmetical and logical functions, referred to as operators**Fig. 32**. Examples of applicable operators include:

| | |
|---|---|
| o | OR |
| & | AND |
| S | Split |
| < | Less than |
| > | Greater than |
| + | Sum |

The operator is placed inside a circle or a diamond, depending on how the functions are implemented, as illustrated in Fig. 30:

- A circle indicates software implementation,
- A diamond indicates hardware implementation, i.e., using relays, switches, and solenoid-operated valves as appropriate.

Many control system manufacturers have implemented their own library of these function blocks based on the specifications in IEC PAS 63131 (which they do). The actual logical operations are configured by connecting function blocks from the library.

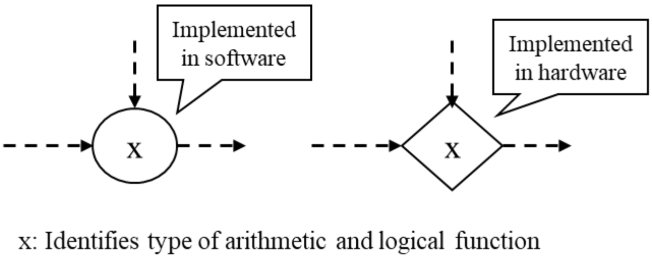



**Fig. 30. Arithmetic and logical function symbols**

### 3.5.3.9 SCD example 1

Fig. 31 describes two logical functions: level control and PSD-initiated activation of a shutdown valve.

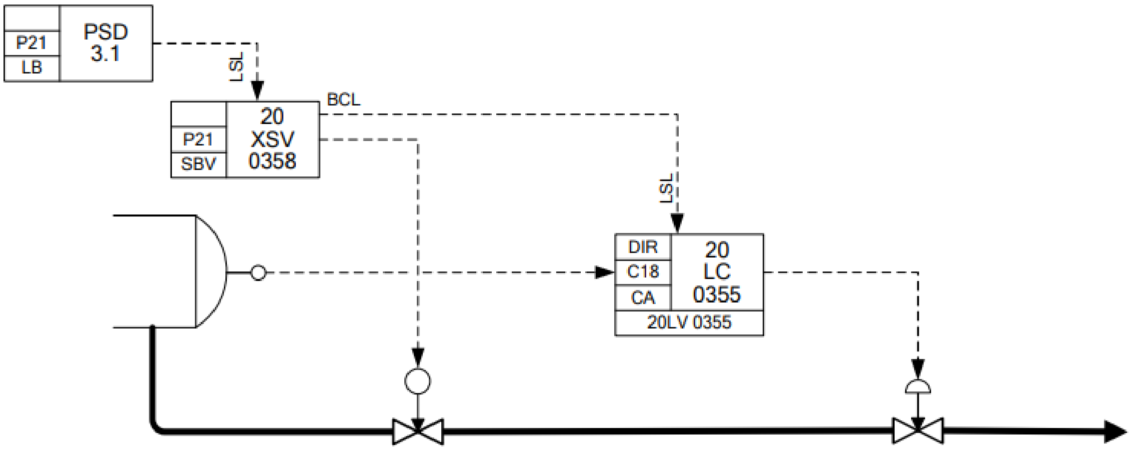



**Fig. 31. Extract of a system control diagram (SCD) (from IEC PAS 61131)**

The level control function may be explained as follows:

- The CA block reads the analogue measurement from a level transmitter. The tag number is not identified, as the MA block has been skipped, but we can guess it is 20-LT-0355.
- The CA block performs PID control(20-LC-0355) and adjusts the position of the LCV valve, not identified by tag-number, but we can assume it is 20-LCV-0355.

Based on industry practice, it seems that it is common to also add MA and OA block to ensure that the operations related to reading input and setting output values from the control function are properly identified.

Similarly, the PSD function may be explained as follows:

- The PSD activation starts with the LB block that will provide a low (off) signal connecting to the LSL input (low safeguard low) of the SBV block, forcing the output of the SBV block to enter its lowest value (0) and maintain this state until reset.
- Another output of the SBV block (BCL – output position low confirmed) connects to the LSL input of the CA block, causing the PID block to force its output to its lowest value. It means that the control valve, upon a PSD shutdown, will also close, not only the shutdown valve

  - It is often added when a specific PSD or ESD level activates a field device. The abbreviation LSL stands for "lock safeguarding low".
  - In this example, it sends a command (LSL=1) that forces the SBV block's output to zero (low), regardless of the SBV function block being in automatic or manual mode, causing the valve to enter the fail-safe position.
  - The only way to prevent the valve from closing is if the SBV block has been blocked. Blocking safety functions generally requires a work permit, and compensating measures must be in place while the function is unavailable.
- The SBV block converts the received input to an on/off state at the output card pin. In the off-state, the solenoid valve 20-XSV-0358 switches to the closed position, closing the shutdown valve.
- As a backup, the LB blocks send a binary command to the CA block in a low-level situation. The CA block will also force the level control valve to close.

As we cannot share the full specification of the IEC PAS 63131 standard, we simplify our notation to avoid including information such as LSL, BCL, etc. Instead, we use the notations AHH and ALL for alarm trip high and alarm trip low with respect to the MA block when the binary output is applied. For other blocks, we will add an explanation as needed.

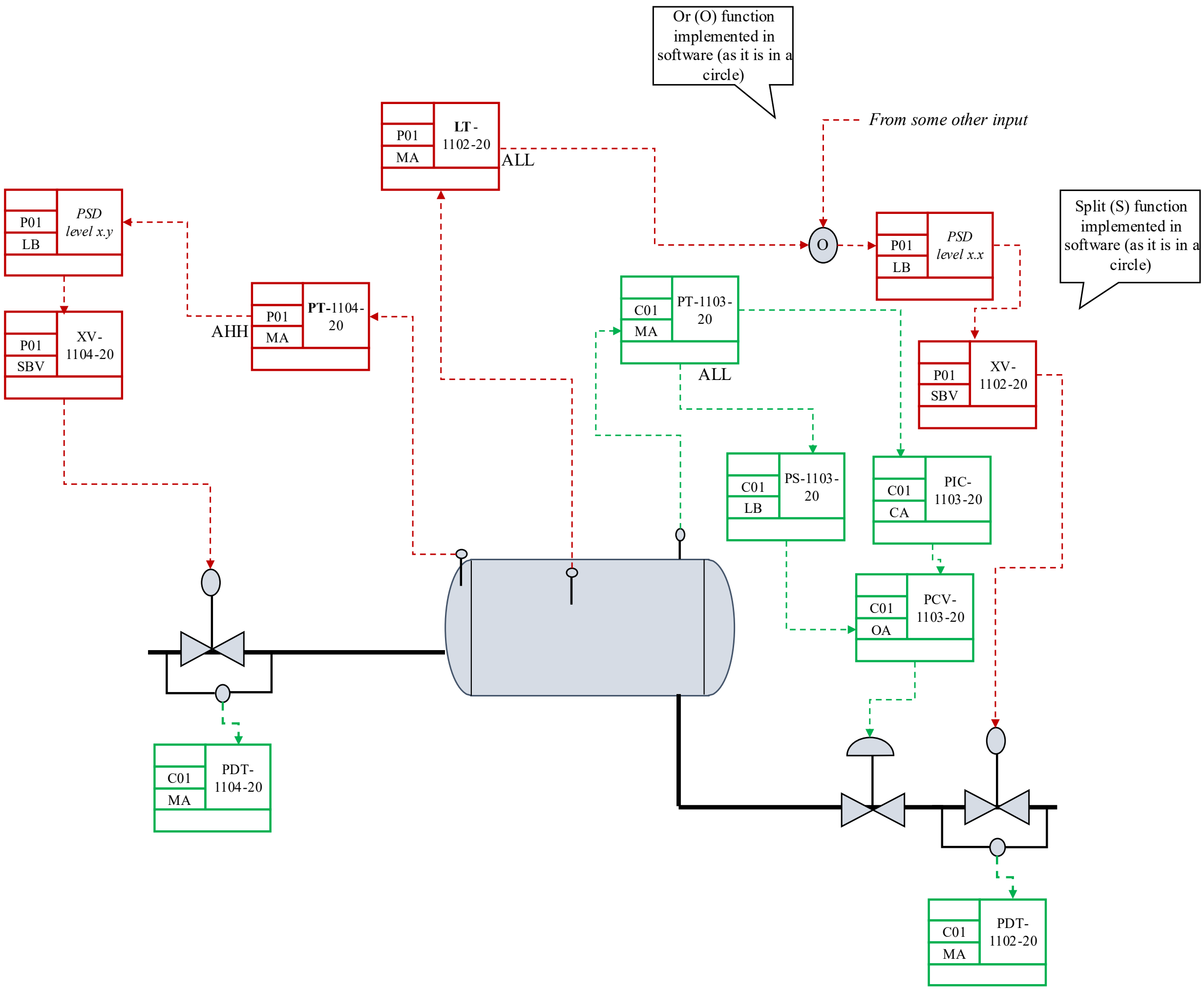



**Fig. 32. Using SCD to illustrate a control and a safety function**

### 3.5.3.10 SCD example 2

Fig. 32 illustrates two control functions and two PSD functions. The control function is interpreted as follows:

PID control (pressure)

- An MA block reads the measurement from the pressure transmitter PT-1103-20 and converts the reading to a digital value sent to the CA block.
- The CA block performs PID control to decide on the control signal to the pressure control valve PCV-1103-20.
- More recent industry practice is to also add an OA (analog output) function block after the CA block, giving improved functionalities for switching manual and automatic valve operation, configuring output limits, and handling overrides.

On/off function:

- A binary value is also sent from the MA block for PT-1103-20 to the LB block if the pressure is below a preset threshold (ALL).
- The LB block, representing a close/open function denoted PS-1103-20, is forcing the valve to close via the OA block, regardless of the control signal from the PIC-1103-20 controller.
- This example shows that an LB block can also be used for implementing simple logical operations in the control system.

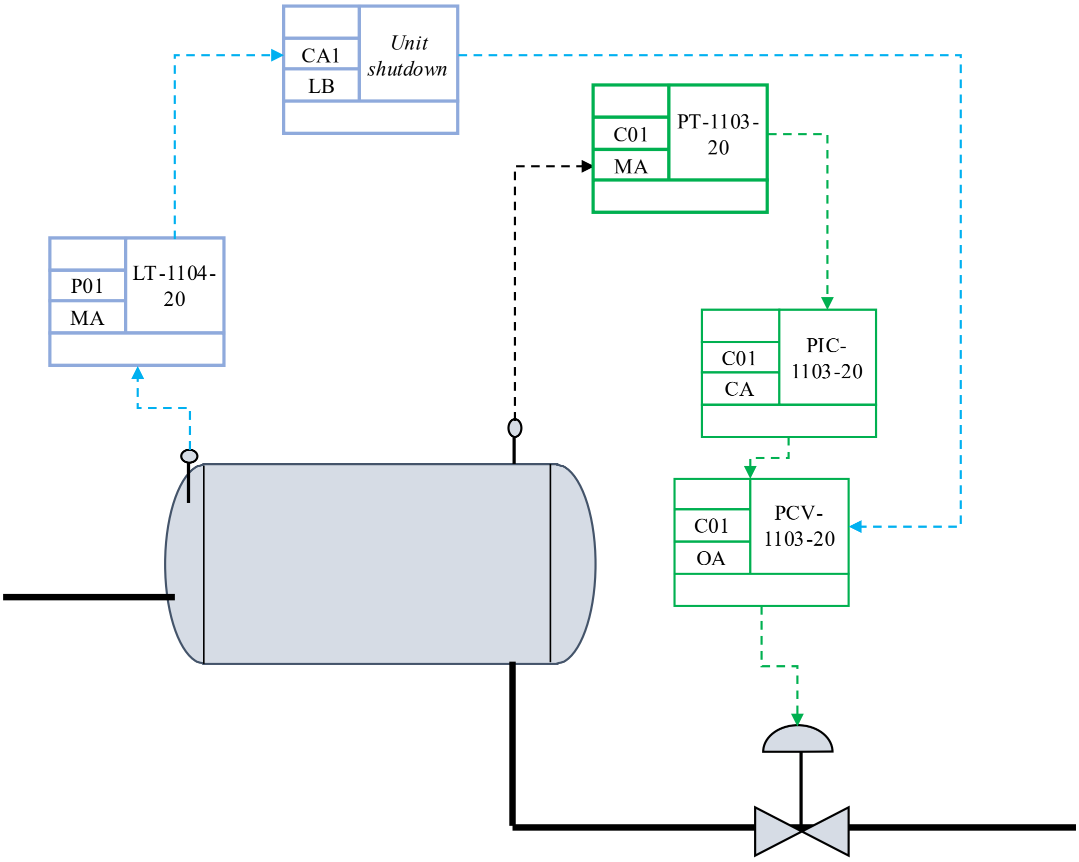



**Fig. 33. Forcing a PID loop to set output to its lowest value**

The PSD function "low-level protection" can be explained as follows

- The MA block receives the measurement from level transmitter 20-LST-1102.
- The MA block outputs a binary value (corresponding to TRUE) if the measurement passes the highest setpoint (action alarm high-high, abbreviated as AHH) and the lowest setpoint (action alarm low-low, abbreviated as ALL). The ALL output is part of the PSD function.
- The LB block identifies that the PSD function is part of a PSD shutdown level. An OR function has been added to allow the same shutdown level to be triggered on another input. The LB block receives input via the LSL input, so the output is also forced to zero.
- The SBV block receives the command from the LB block via its LSL input, forcing the output signal to zero to close the on/off valve.
- Associated with the PSD function, but part of the basic control system, is the MA block that monitors the position of the valve, using a differential pressure transmitter, PDT-1102-20. This transmitter value will show whether the valve is fully open or closed.

After consultation, it seems that industry practice is to always include LB blocks for ESD and PSD functions, as both systems incorporate shutdown levels in addition to the individual SIFs.

PSD function "high-pressure protection" is straightforward to interpret following the same reasoning as for the "low-level protection".

#### 3.5.3.11 SCD examples 3 and 4

The last two examples identify some additional functions that can be implemented:

- Fig. 33 explains how the LB function, implemented in a control system, can force an OA block to set the minimum output value, thereby causing a control valve to enter the closed position.
- Fig. 34 illustrates how transmitter voting can be implemented, here with the example of a 2oo3 (two out of three) voting of three pressure transmitters. This is one of two variants shown in IEC PAS 63131.

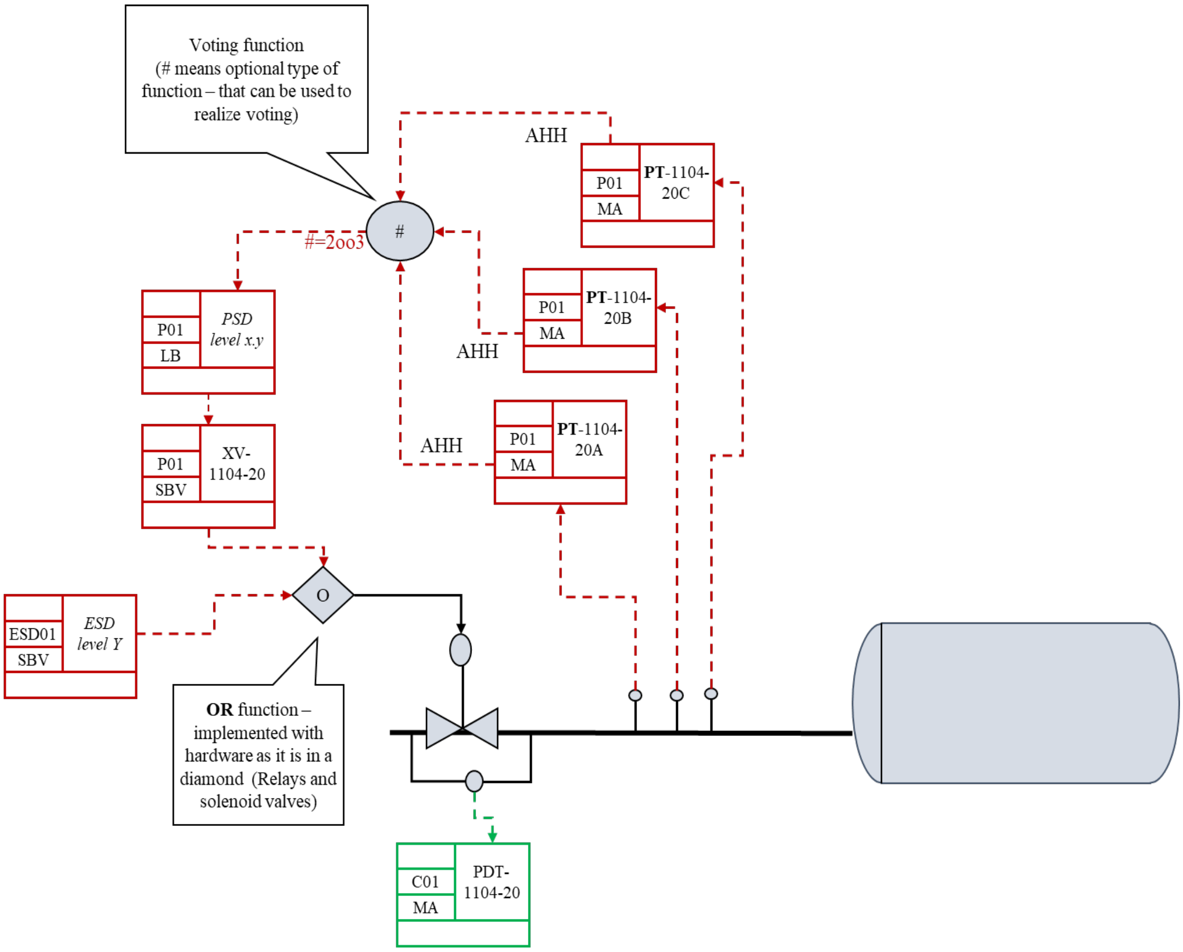



**Fig. 34. Implementing voting in an SCD**

### 3.5.4 C&E diagram

A Cause and Effect (C&E) diagram models the relationship between inputs ("cause") and actions performed ("effects") of safety-instrumented functions in a *matrix* format. The formalism and standardization of C&E diagrams are given in IEC 62881 (2018). The layout follows the structure in Fig. 35, with causes (or initiators) listed in the left column, effects listed at the top of subsequent columns, and intersections marked when a specific cause has one or more specific effects.

The document serves several purposes:

- Basis for programming/configuring logic for safety instrumented functions (SIFs).
- Basis for testing the implemented logic.
- Support operators when handling an emergency.
- Support to operators when planning temporary inhibiting and overriding of safety functions during modification work.

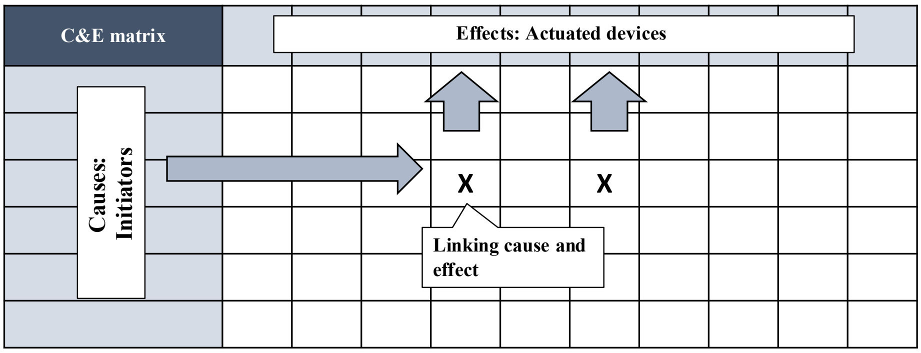



**Fig. 35. General layout of a C&E matrix (IEC 62881)**

C&E diagrams are used to specify functions implemented by PSD, ESD, and F&G systems. A separate drawing set is often created for each of the three systems.

Tab. 3 shows a simplified C&E diagram for a simple fire and gas (F&G) detection system monitoring a workshop located near the process area at a facility. By "simplified," it means that the individual inputs and outputs (effects) are not identified by tag numbers. The letter “X” is used to mark whether the output is activated when the input is triggered. The matrix is interpreted as follows:

1. The ventilation is stopped upon a gas concentration of 20% LEL (lower explosion limit), a detected fire (flame detector), or a manually pressed fire alarm button. At the same time, an alarm is raised in the control room.
2. Upon detecting 60% (LEL) gas, the emergency shutdown system (ESD) is activated, and a new alarm is raised in the control room.
3. Confirmed detection with the flame detector initiates the ESD system and starts the fire extinguishing systems
4. Manual fire detection via pushbuttons in the workshop also activates the ESD system and starts the fire extinguishing systems.

**Tab. 3. C&E matrix for a F&G detection system**

| Causes | | Effects | | | | |
|---|---|---|---|---|---|---|
| **Input** | **Trip point** | **Stop ventilation** | **Alarm control room** | **Activate Emergency shutdown (ESD)** | **Close fire dampers** | **Start extinguishing systems** |
| Gas detection | 20% | X | X | | | |
| Gas detection | 60% | | X | X | X | |
| Flame detection | Confirmed | | | X | | X |
| Manual fire detection (push button) | Activated | | | X | | X |

Tab. 4 shows an example of a C&E matrix for some of the functions implemented in a process shutdown system (PSD). Here, the individual inputs and outputs are identified by tag numbers assigned specifically to this example. Additional details added for the inputs are alarm trip points and voting. The combinations of inputs and outputs are shown by the letter “X” or “T1”. “T” denotes a time-delayed activation, and “1” indicates that additional timer options are available; we selected “T1”.

**Tab. 4. C&E matrix for process shutdown**

| Causes | Effects |
|---|---|

| | | | | XV-2001A | XV-2001B | XV-2005 | XV-2005 | XV-2006 |
|---|---|---|---|---|---|---|---|---|
| **Inputs** | **Alarm** | **Trip point** | **Voting** | **Open** | **Open** | **Close** | **Open** | **Close** |
| PT-001A | HH | 35 bars | 2oo3 | X | X | | | |
| PT-001B | HH | | | X | X | | | |
| PT-001C | HH | | | X | X | | | |
| TT-004A | HH | 170 ºC | 1oo2 | | | | | X |
| TT-004B | HH | | | | | | | X |
| LT-006A | HH | 78% | 1oo2 | | | T1 | | |
| LT-006B | HH | | | | | T1 | | |
| LT-006A | LL | 15% | 1oo2 | | | | X | |
| LT-006B | LL | | | | | | X | |

C&E diagrams are generally more complex than the examples that we have provided, but the principal way of reading them is the same.

## 3.5.5 ESD hierarchy

Some plants prefer to use both the C&E and shutdown hierarchies as ways to show how safety functions are triggered and their corresponding actions. The shutdown hierarchy provides a high-level overview and is read from top to bottom. It is quite helpful in showing how an emergency shutdown system operates at different levels or stages. An emergency can have varying levels of criticality, and adjusting actions accordingly is beneficial and safe. The horizontal lines indicate the stages and levels within the emergency shutdown system, with vertical arrows connecting inputs to outputs. The simplified version of the generic shutdown hierarchy presented in the technical safety specification NORSOK S-001 (2021) is shown in Fig. 36**.**

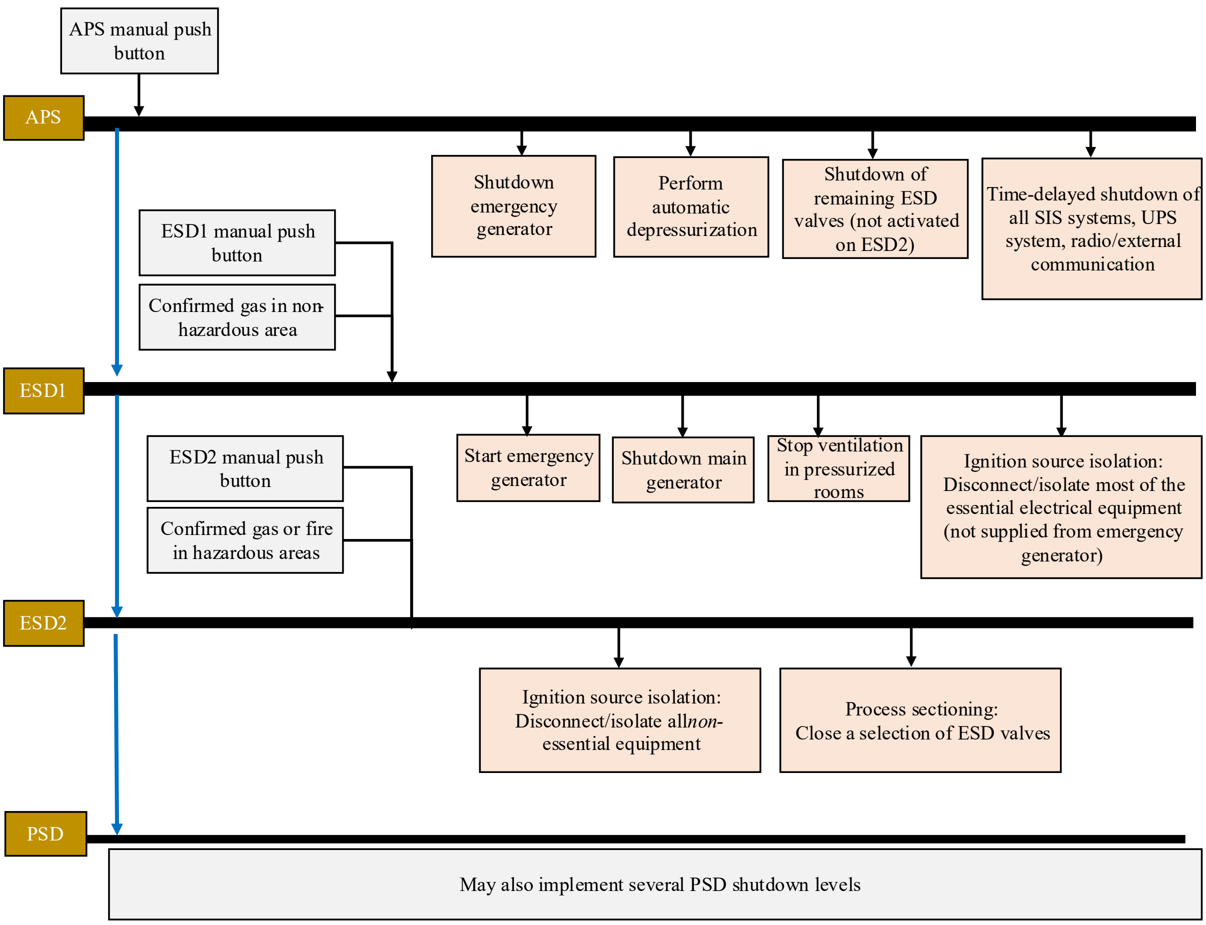



**Fig. 36. Simplified ESD shutdown hierarchy (inspired by NORSOK S-001)**

Based on this specific hierarchy, we can retrieve the following information:

The ESD system is divided into three levels, ordered by authority: the Abandon Platform System (APS), ESD1, and ESD2. APS is activated in an uncontrollable situation, and people muster at the lifeboats to leave the facility.

- The ESD levels are activated by different inputs that represent different scenarios and criticalities, but a higher level always and automatically activates the levels above it.
- The lowest ESD level (ESD2) always initiates the process shutdown system (PSD) so that all PSD-related equipment is closed (valves) or stopped (rotating equipment).

With reference to Fig. 36, we can retrieve the following information:

- APS can only be initiated manually. When activated, the following will occur:
    - Stop the emergency generator (this means that only equipment with its battery backup continues to be powered*)
    - *Delayed shutdown of all safety systems, including power supply from battery systems
    - Closure ESD valves not yet closed at ESD2
    - Automatic depressurization to flare system (using blowdown valves)
    - Initiate ESD1
- ESD1 can be automatically activated because of APS, by ESD1 manual initiation (push buttons), and by confirmed gas or fire detection in non-hazardous areas, such as control rooms and living quarters. Non-hazardous areas do not mean they are not hazardous, but are normally considered safe, such as in living quarters and offices where gas should not appear. Once ESD1 has been activated, the following will occur:
    - Stop the main generator, so electrical equipment not supplied via an emergency generator loses power (ignition source.
    - Shutdown ventilation (so that dampers close to not allow more gas to enter)
    - Start emergency generator
    - Initiate ESD 2
- ESD2 can be automatically activated because of ESD1, by ESD2 manual initiation (push buttons), by having confirmed fire or gas detection in process areas ("hazardous area"). Once ESD2 has been activated, the following will occur:
    - Disconnect non-essential electrical equipment without stopping the main generators.
    - Closure of a selection of ESD valves
    - Initiate complete PSD shutdown.

### 3.5.6 Electrical circuit diagram

An electrical circuit diagram is a graphical representation of the physical connections and layout of an electrical system or circuit with switches, contactors, wires, and motors. Drawings are needed to understand when and how the electrical devices are operated. The format is standardized with IEC 61802 (2014), but variants may still exist.

Take a look at this YouTube video about electrical wiring diagrams.

Two examples of electrical circuit diagrams for controlling a motor are shown in Fig. 37. We can interpret the information in the diagram to the left as follows:

- The three-phase power supply is applied if the safety switch S0 is closed. The safety switch can be opened or closed from a panel.
- For the motor control system to receive a power supply, the three contactors' coils K1, K2, and K3 must be energized so that the corresponding contact sets close.

A contactor consists of a coil and one or more switches that operate when the coil is energized or de-energized. The diagram to the right explains how the coil for contactor K1 is being energized:

- Switch S2, operated manually, must be in the closed position

The two diagrams in combination explain what happens when K1 is energized:

- Contacts set with connection points in the terminal strip 53/54 and 83/84.
- Contact sets with connection points in the terminal strip 1/2, 3/4, and 5/6, are closed. If the contacts operated by K2 and K3 are also closed, the motor receives power.

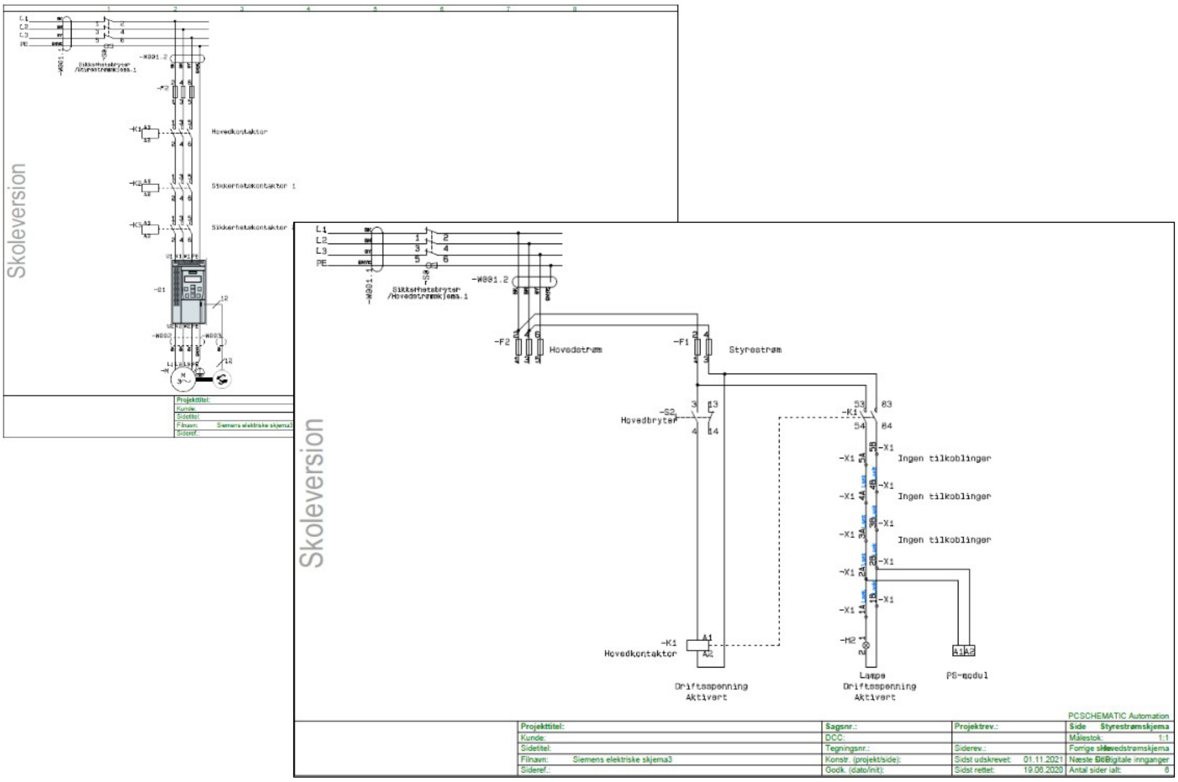



**Fig. 37. Electrical wiring diagram**

## 3.5.7 Instrument loop diagram

An instrument wiring diagram (also called a loop diagram) provides information about the physical layout and routing of signal transmission circuits. While an electrical wiring diagram shows the layout of power supply circuits, an instrument wiring diagram shows the layout of signal transmission circuits.

YouTube has a couple of useful videos about instrument loops, such as video 1 and video 2 .

Fig. 38 shows an example of an instrument loop diagram. From this drawing, we observe the following:

- The drawing identifies the field instrument (a pressure transmitter PT-123)
- The cable from the pressure transmitter is a 2-wire cable (i.e., one pair). The drawing indicates that one wire is white and the other is black. This cable is routed to the junction box labeled JB-57846.
- Inside the junction box, it is indicated which terminal block is being used (004). The two wires exiting the JB are red and blue, not black and white. The cable containing the wires consists of two pairs (i.e., one additional pair).
- The two wires are terminated in an IS barrier when they enter the first control panel, PLC cabinet 4. The IS barrier is a terminal block that can separate (galvanically) and redirect (via Zener diodes) the current to the earthing system in the event of an electrical fault, thereby avoiding excessive energies that could ignite gases or dust. The two wires enter terminals 1 and 3 and exit the barrier at terminals 7 and 8. The wires leaving terminals 7 and 8 are routed to another terminal block inside the control panel, where they connect to terminals 9 and 10.
- The screen is connected to an intrinsically safe (IS) earth system protected from other earth systems.

- The two wires are then routed to an input card for a PLC located in PLC cabinet 5. The loop diagram provides information about the I/O card number, the PLC/DCS node it belongs to, and the number of channels it has.
- Last, the loop diagram identifies what type of information about PT-123 is displayed on the operator screen. In addition to the measurement value, it has a setpoint for HH and LL.

Note that the layout and symbols used in electrical wiring and instrument loop diagrams may vary by country and across industrial sectors. Often, the drawings will have a first or last sheet explaining the notations.

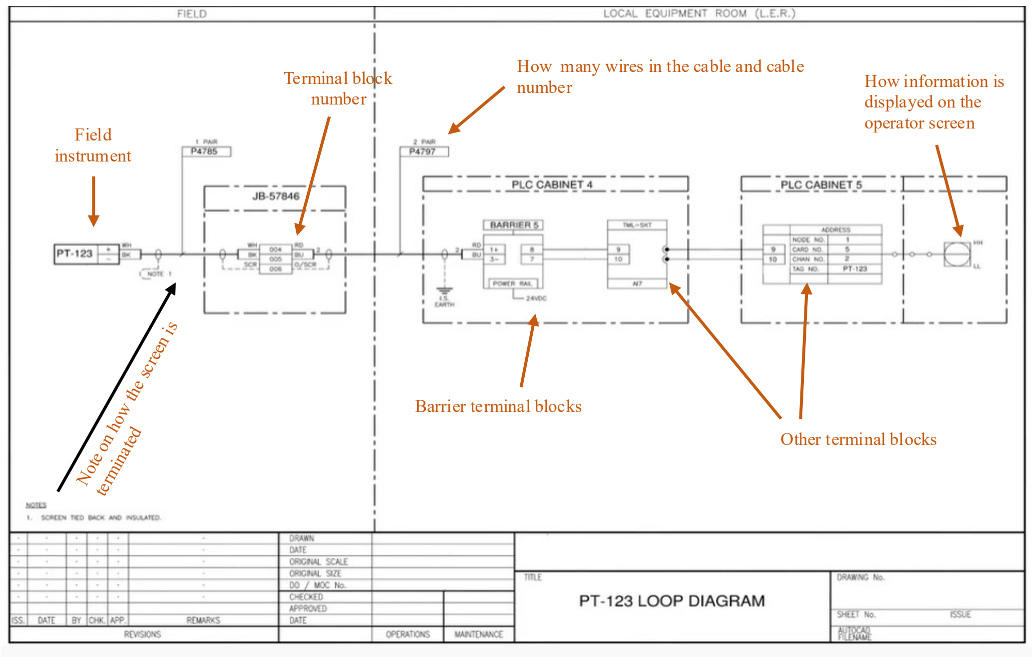



**Fig. 38. Instrument loop diagram**

## 3.5.8 Pneumatic and hydraulic circuit diagrams

Pneumatic and hydraulic circuit diagrams are two types of schematics for (respectively) the pneumatic and hydraulic control valve operations, including pipes, filters, restrictors, and supply systems (pumps, compressors). The standards to visit to learn more about diagrams and diagram symbols are:

- ISO 1219-1 (2012): Fluid power systems and components - Graphical symbols and circuit diagrams - Part 1: Graphical symbols for conventional use and data-processing applications
- ISO 1219-2 (2012): Fluid power systems and components - Graphical symbols and circuit diagrams - Part 2: Circuit diagrams

Unfortunately, the author did not identify any good examples of complete, readable diagrams online, but the most important symbols for our usage, the pneumatic and hydraulic DCV valves, have already been explained. What is added to such diagrams, besides the DCV valves, are mechanical regulators, filters, and relief valves, as well as sources of pressurized air (compressors and dryers) or hydraulics (pumps and a return tank).

A YouTube video explaining a hydraulic circuit diagram. (It is part of a series on hydraulic power unit schematics from "The Lunch Box Sessions"). Microsoft Visio also has symbols for drawing pneumatic and hydraulic control diagrams, and its support page has a sample drawing (unfortunately, the small text is not easy to read). Samples may also be found in papers via e.g., ResearchGate.

## 3.5.9 Terminal blocks and labeling of wires

Hardwired individual measurement or control signals (analog 4-20 mA or binary) and power supply are usually transferred from one location to another via several cables. Wires used for the transmission are transferred from one cable to the next via terminal blocks like those in Fig. 39. The terminal blocks are mounted in junction boxes (JB), i.e., outdoor enclosures with specialized cable entry solutions, and in control panels or cabinets in indoor equipment rooms.

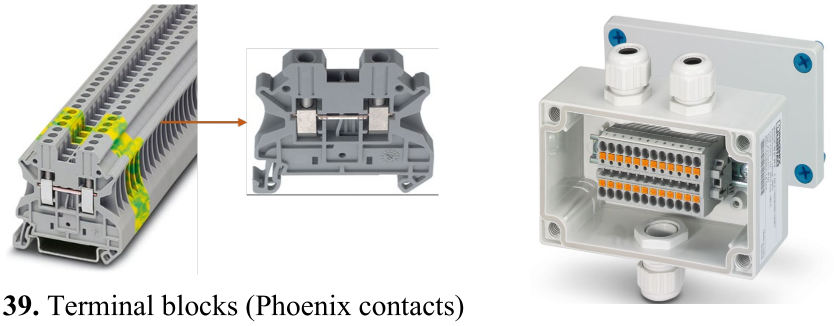


**Fig. 39.** Terminal blocks (Phoenix contacts)

Fig. 40 illustrates how cable wires connect to terminal blocks. Each terminal point of a terminal block is numbered identically on both sides, and terminals with the same number are connected. Jumpers may be added if a signal in one wire is forwarded to multiple destinations via separate wires.

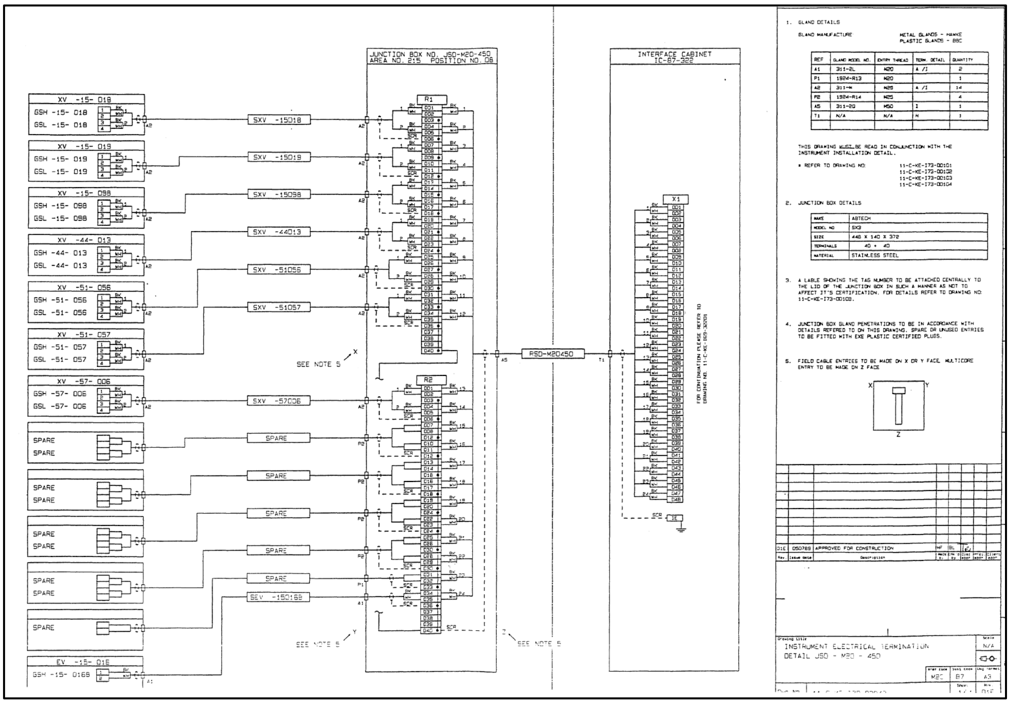


**Fig. 40. Labeling of cables and terminals**

An example of how the inside of a cabinet may look is shown in Fig. 41. First, note that (primarily) white labels are added to the wires. Both ends of each wire and the cable are labeled. The labeling must match the numbering/coding in the electrical wiring diagrams. Cables are labeled inside cabinets (if possible) and outside near the cabinet entrance.

The cable and wire labels are essential for many reasons:

- In case you need to disconnect the power supply or a signal, you must verify that you have selected the correct wires.
- For troubleshooting in response to fault signals, short circuits, or earthing faults, you need to select the most relevant wires and cables for analysis.

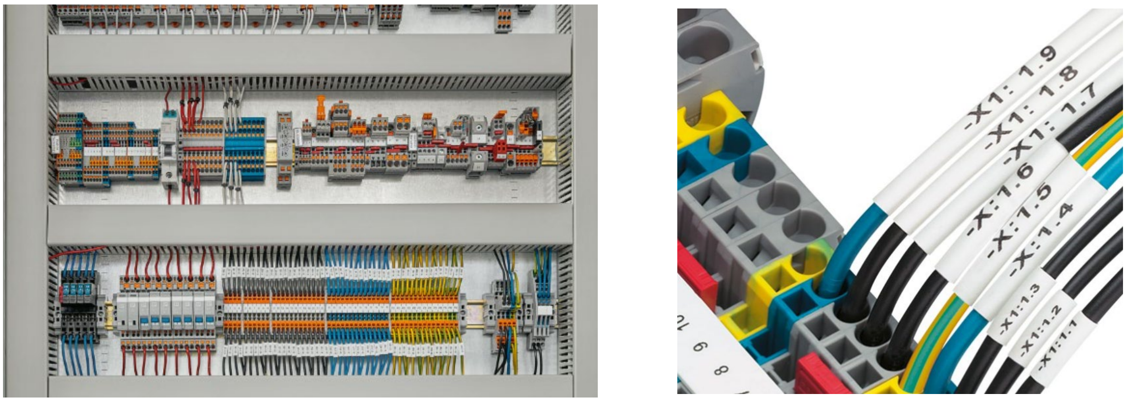


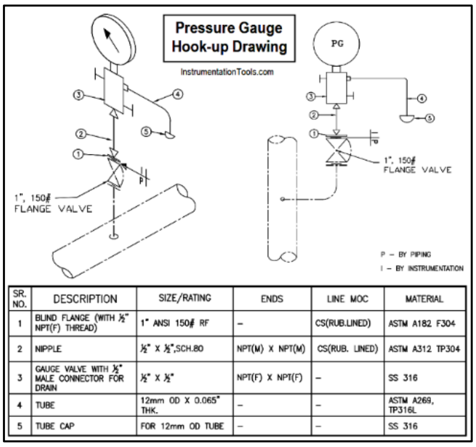
**Fig. 41. Looking inside a cabinet (Phoenix contacts)**

Labels for cables in the field must withstand exposure to weather, wind, and corrosion, and must be considered when selecting materials and fastening mechanisms.

| | |
|---|---|
|  | A YouTube video explaining terminal blocks. |

## 3.5.10 Assembly drawings

Assembly drawings (also known as hook-up drawings) provide detailed instructions for mechanically installing the field device, including tube/pipe connections for the instrument and/or hydraulic supply, as well as the method of mounting the instrument onto or into the process equipment (such as a tank or pipeline). Dimensions and other details are shown. Fig. 42 shows two examples of assembly drawings.




| SR. NO. | DESCRIPTION | SIZE/RATING | ENDS | LINE MOC | MATERIAL |
|---|---|---|---|---|---|
| 1 | BLIND FLANGE (WITH ½" NPT(F) THREAD) | 1" ANSI 150# RF | – | CS(RUB.LINED) | ASTM A182 F304 |
| 2 | NIPPLE | ½" X ½",SCH.80 | NPT(M) X NPT(M) | CS(RUB. LINED) | ASTM A312 TP304 |
| 3 | GAUGE VALVE WITH ½" MALE CONNECTOR FOR DRAIN | ½" X ½" | NPT(F) X NPT(F) | – | SS 316 |
| 4 | TUBE | 12mm OD X 0.065" THK. | – | – | ASTM A269, TP316L |
| 5 | TUBE CAP | FOR 12mm OD TUBE | – | – | SS 316 |

**Fig. 42. Assembly or hook-up drawings**

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