6. Typical discrete input and output devices

6.1 Discrete input devices

- Manual switches and push buttons. They are used to initiate or select process operations or input values by the system operator. They can have single or multiple contacts. The contacts in multiple contact switches (e.g., thumbwheels) or multiple contact push buttons (e.g., keyboards) operate simultaneously. If connected to a PLC, each contact occupies one PLC input!

- A keypad with conductive rubber contacts: each pushbutton, when depressed, produces the signal state 1 in the two output lines representing its row and column in the matrix.

- Limit switches

- Proximity switches

A metallic object placed close to an inductive proximity switch changes the inductance of the device sensing coil. An object, which can be nonconductive, placed close to a capacitive proximity switch changes the capacitance of the device sensor. The change is detected by the electronic circuit of the device and results in the operation of the electronic switch.
Two-wire proximity switches are available, where the device internal circuit is supplied through the switched circuit.

The PLC input current of a few mA is sufficient to supply power to the proximity switch.

**Photoelectric switches**

- Light beam (photoelectric barrier)
- Photodetector
- PLC input
- Object
- PLC input

**Encoders**
Incremental encoders

The number of the photodetector pulses (e.g., counted by a PLC) is a measure of the angle through which the disc has rotated. This type of encoder is used for speed and distance measurement.

Incremental encoders often supply a second signal (B) that is offset by $\frac{1}{4}$ of a cycle from signal A. It is used to determine the direction of rotation and also increase the resolution. Signal Z is a once-per-revolution index (zero-mark) pulse.

Absolute encoders

This type of encoder is used for position measurement. The number of tracks in the binary code pattern on the disc determines the angular resolution. In the example shown: 3 tracks $\rightarrow$ 3 bits $\rightarrow 2^3 = 8$ discrete positions $\rightarrow$ angular resolution $= \frac{360^\circ}{8} = 45^\circ$.

The actual disc of an 8-bit absolute encoder (Grey code) Output waveforms from a 6-bit absolute encoder (Binary code)
The encoder measures the position of a work table through a ball screw.

The encoder determines the relative position, direction and speed of travel in a bi-directional conveyor belt.

The encoder measures the distance travelled for a cut-to-length operation.

The encoder measures the position and velocity of the rack and pinion.

Applications of encoders

An encoder is to be selected for the cut-to-length system shown in the previous slide. The material travels at a speed of 12 m/min. The circumference of the friction wheel is 0.25 m. The measurement of the distance travelled by the material requires a resolution of 0.1 mm. The encoder is to be connected to a PLC. The maximum frequency of the input signal acceptable by the PLC is 10 kHz.

1. Determine the type of the encoder and the signals needed for the measurement?
2. Find the number of pulses per turn the encoder is required to provide.
3. Check, if the PLC is suitable for processing the encoder signals.

Answer:
1. Only signal ‘A’ from an incremental encoder is needed.
2. Number of pulses per turn: \( N = 0.25/(0.1 \times 10^{-3}) = 2500 \) pulse/turn
3. Signal ‘A’ frequency: \( f = (12 \times 2500)/(0.25 \times 60) = 2000 \text{ Hz} < 10 \text{ kHz} \)
Other switches

In this category, there are mechanical and electronic switches that close/open in response to changes in such process variables as temperature, pressure, flow rate, liquid level, etc. Many of these switches can be of a simple mechanical design (eg. bimetallic temperature switches, liquid level switches with a float, flow switches, etc.)

6.2 Discrete output devices

- **Contactors**
- **Solenoid valves**

![Diagram of solenoid valve and its components]
Solenoid valves are used to control the flow direction of pressurised air or oil in order to control the operation of a mechanical device, such as a piston moving in a cylinder. The movement of the piston can be utilised to rise/lower parts of a machine, clamp objects, push items off a conveyor belt, etc.

Graphical symbol of the hydraulic solenoid valve shown on the previous slide. The connections are always shown for the state when the solenoid is not energised (normal state).

Example

When no solenoid is energised, the barrier stays in the acquired position.

If this type of cylinder is used, only one s. valve is required

Pneumatic valves

7. Digital input and output modules

7.1 Input modules

The digital (discrete) input signals of a PLC can come from various field devices containing mechanical or electronic switches (see Section 3). These signals can be either DC or AC and have nominal values ranging from 5V to 240 V. In general, they have to be properly interfaced with the CPU, as it operates at a low DC voltage level and is sensitive to interference.

A typical PLC input module:

- provides electric (galvanic) isolation between the field input circuits and the CPU;
- converts the voltage level of the input field device signal to the level at which the CPU operates;
- protects the CPU from abnormally high voltages in the input circuit due to switching transients (voltage spikes) or faulty conditions;
- limits the interference that may affect the input signal (ground loops broken by the isolation barrier, filters).
1. If the contact of the field input device is closed (SS=1), the indicator LED and the LED of the optocoupler (optoisolator) are lit.
2. As a result, the phototransistor of the optocoupler is saturated (in ON state) and its collector voltage is low (SS=0).
3. The signal from the optocoupler is inverted in the buffer so that the CPU receives the same signal state as the input of the module.

**PLC DC input circuit**

1. If the contact of the field input device is closed (SS=1), the indicator neon lamp is lit. The optocoupler LED is lit by a rectified sinusoidal current from the diode bridge.
2. Consequently, the optocoupler phototransistor remains in saturation most of the time. Its collector voltage stays low continuously, due to the filter formed by R2 and C.
3. The signal from the optocoupler is inverted in the buffer, so that the CPU receives the same signal state as the input of the module.
### 7.2 Output modules

The output field devices connected to a PLC operate at different voltage levels, usually higher than that of the CPU. The output connections from the PLC can carry inference back to the CPU.

For these reasons, a typical **PLC output module**:

- provides electric (galvanic) isolation between the field output circuit and the CPU;
- converts the voltage level required by the output field device to the level of the CPU output signal;
- protects the CPU from abnormally high voltages across its output terminals due to switching transients (voltage spikes) or faulty conditions in the output circuit;
- limits the interference that may affect the CPU.

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**PLC DC output circuit**

1. If the CPU output signal state is 1, transistor $V_1$ and the phototransistor of optocoupler $V_2$ are on. Transistor $V_3$ is also on, as the emitter current of the phototransistor drives the base of transistor $V_3$. It now acts as a closed switch in the output load circuit.
2. Zener diode $V_4$ acts as a free-wheeling diode, if the field output device is inductive. It also protects transistor $V_3$ from inverse polarity or excessive value of the voltage across the output terminals.
PLC AC output circuit

1. If the CPU output signal state is 1, transistor $V_1$ and the phototransistor of optocoupler $V_2$ are on. The phototransistor conducts a dc current rectified by the diode bridge and limited by resistor $R_3$.
2. The current on the AC side of the diode bridge flows through the gate of TRIAC $V_3$. This current triggers the TRIAC every half period of the voltage in the load circuit. $V_3$ acts now as a closed switch.

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PLC AC output circuit with relay switching

1. If the CPU output signal state is 1, transistor $V_1$ conducts the current that energises the coil of the miniature electromechanical relay. The state of the N/O contact of the relay is the same as the SS of the CPU signal.
2. The field power supply in the output circuit can be DC or AC. The frequency of the output switching is low.
8. Analog signals in PLC systems

8.1 Types of analog signals

An electric analog signal is either voltage or current that varies within a predetermined (nominal) range of values. Typical nominal ranges are:

A voltage signal \( v(t) = \begin{cases} 
0 - 10 \text{ V} \\
0 - 5 \text{ V} \\
-10 \text{ V} - +10 \text{ V}
\end{cases} \)

A current signal \( i(t) = \begin{cases} 
4 - 20 \text{ mA} \\
0 - 20 \text{ mA}
\end{cases} \)

Using current to transmit analog signals has the following advantages:

- Current signals are more immune to interference than voltage signals, since its value is unaffected by voltage drops in the conductors, stray thermocouples, contact resistance, and noise voltage due to capacitive and inductive coupling.

- The offset of 4 mA (in the case of 4 – 20 mA signal) provides a distinction between zero signal represented by 4 mA and no information due to an open circuit.

Current-to-voltage conversion can be done simply by passing the current signal through a resistor and utilising the voltage drop across the resistor as the converted voltage signal. Reversed conversion requires a voltage-to-current converter.

\[
V_{\text{interference}} = V_{\text{cap. coupl.}} + V_{\text{ind. coupl.}} + V_{\text{contacts}} + i R_{\text{line}} + \ldots
\]

The source of the signal (an electronic system) can receive power supply via the 4 mA component that is not needed for information transfer.

Current-to-voltage conversion can be done simply by passing the current signal through a resistor and utilising the voltage drop across the resistor as the converted voltage signal. Reversed conversion requires a voltage-to-current converter.

Analog signal transmission circuit with voltage-to-current conversion
8.2 Interference considerations

$C_{cn}$ is the equivalent coupling capacitance between the signal circuit and the circuit which is the source of interference. $R$ is the input resistance of the system receiving the signal. The interference voltage (electrostatic pickup, capacitively coupled noise), which is added to the signal voltage, is, therefore, $R \frac{d}{dt} i_n$.

The electrostatic pickup can be reduced by proper orientation and separation of the coupled conductors (it decreases the value of $C_{cn}$ and, subsequently, $i_n$) or by shielding. The shield is placed around the signal conductors and must be connected to ground.

If a shield is employed, current $i_n$ flows into the shield, instead of the signal conductor, and is drained to the ground without affecting the signal circuit.

Separating the coupled circuits and minimising their loop areas reduces the inductive pickup ($\Phi_{cn} \frac{d}{dt}$). Shielding against inductive pickup is ineffective, as magnetic fields penetrate deep into metals at low frequencies.

A twisted pair of conductors is widely used for signal wiring to reduce inductive pickup. It minimises the loop area in the signal circuit and provides a cancelling effect of voltages induced along the circuit.