Lab 3: Analog Inputs and Outputs on the SIMATIC S7-1200

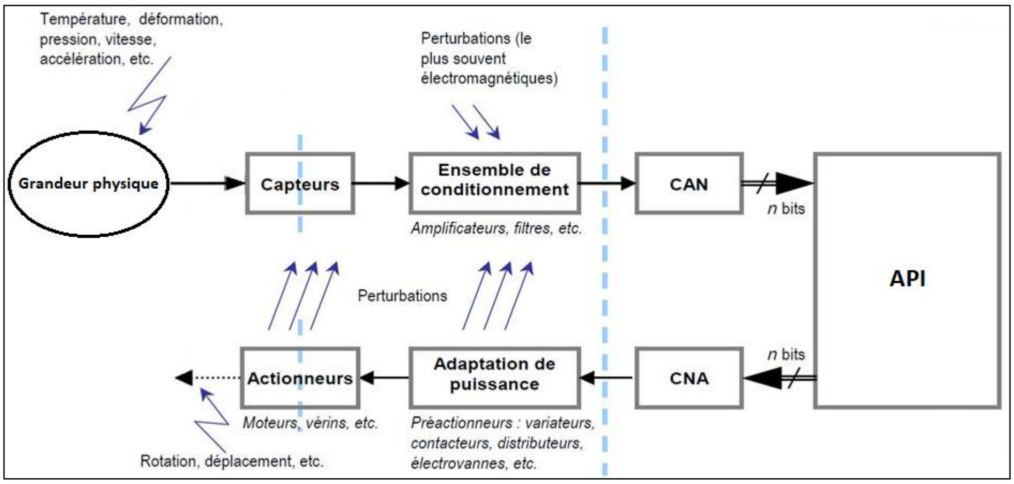
Lab Objective

The purpose of this lab is to demonstrate how to acquire an analog signal using an analog input module and convert it into a digital value that can be processed by the PLC. Through this session, you will learn to:

- Configure analog inputs and outputs on the SIMATIC S7-1200 PLC
- Read data from an analog sensor
- Use the "Comparison" library in TIA Portal
- Simulate the developed program using the PLCSIM simulator

1 Analog Inputs

An analog input is used to receive a variable electrical signal from a sensor within a defined range (e.g., 0–5V). The value of an analog input changes continuously over time based on the physical quantity measured by the sensor. These quantities can include speed, pressure, temperature, distance, and more.
Analog signals coming from a sensor must be conditioned and converted into digital signals in order to be interpreted by the PLC. This conversion is performed by an Analog-to-Digital Converter (ADC) located within the PLC's analog I/O module.



2 Types of Analog Input Signals

There are mainly three types of analog input signals: voltage, current, and **resistance** signals

2.1 Voltage Signals

Voltage-type signals are generated by certain types of analog sensors. The most common operating ranges are **0-5 V** and **0-10 V**.

2.2 Current Signals

The **4–20 mA** current signal has become the industry standard. In some cases, **0–20 mA** signals can also be encountered. (*Example: see Lab 1,* ET 200S, 4AI x **I** WIRE ST)

2.3 Resistance Signals

Resistance-type signals are most commonly used with temperature sensors such as RTDs and thermocouples. (*Example: see Lab 1,* ET 200S Module, 2AI x **RTD** ST)

3 Types of Analog Output Signals

Unlike analog inputs, analog outputs are variable signals generated by the PLC (via analog output modules) to act on analog pre-actuators.

For example, an analog output can be used to control a **variable speed drive** or a **proportional valve**. As with analog inputs, the most common output signal types are **voltage**, **current**, and **resistance**.

4 Processing Analog Inputs/Outputs on the Siemens S7-1200 PLC

4.1 Analog Inputs

Analog values are read by the PLC as 16-bit data words. These words are accessed using specific operands. For example: IW64 (see Figure 2).

- I stands for **Input**,
- W stands for **Word**,
- 64 is the **address** of the analog input.

4.2 Analog Outputs

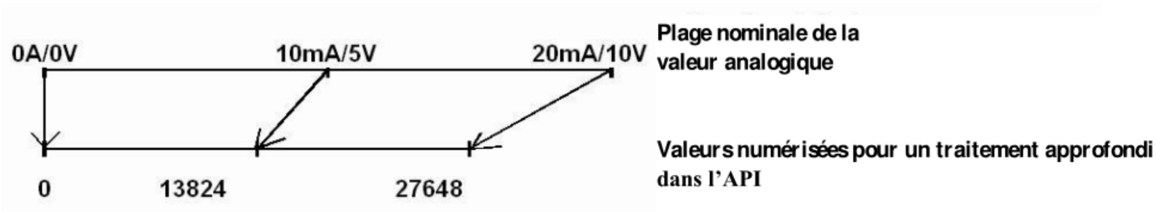
The S7-1214C CPU does not have built-in analog outputs. However, if an external analog output module is available, analog values can be accessed in a similar way. For example: QW80.

- Q stands for **Output**,
- W stands for **Word**,
- 80 is the **address** of the analog output.

Each analog value is assigned to either an input word or an output word. The data format used is **INT** (integer). The addressing of analog input and output values depends on the configuration within the device overview (see Figure 2). For instance, the address of the first analog input might be **%IW64**, and the second one **%IW66**.

4.3 Range of Digitized Analog Values

The conversion of an analog signal for PLC processing is the same for both analog inputs and outputs.
Typical ranges of digitized values include the following:
The digitized value ranges are as follows:



The two analog inputs available on the S7-1214C CPU are configured to acquire voltage measurements within a range of 0 to 10 V.

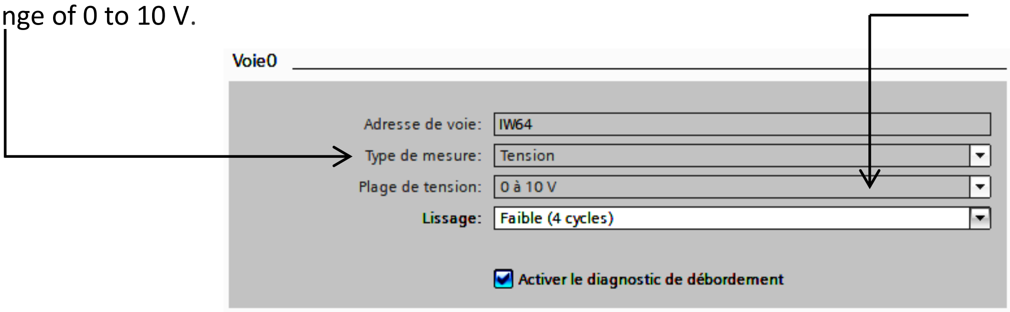


Figure 2. Analog input view in the TIA Portal software

Very important note

The range of digitized analog values chosen by Siemens is fixed and cannot be modified by the user. It is always between **0 and 27648**, regardless of the resolution of the analog-to-digital converter (10-bit, 11-bit, 13-bit, etc.) or the type of analog input signal (voltage, current, resistance, or temperature).

4.4 Representation of Analog Values in Voltage Ranges

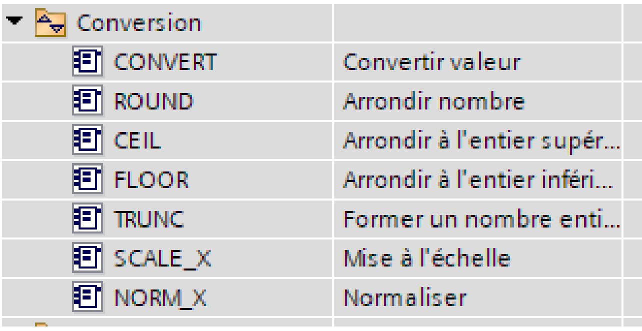
The decimal values (encodings) corresponding to the possible voltage measurement ranges are shown in the table below:

Tableau 1 : Unipolar Input Voltage Ranges

Valeur déc.	Valeur de mesure en %	Plage
32767	>117,589	Déborde-ment haut
32511	117,589	Plage de dépasse-ment haut
27649	100,004	
27648	100,000	
1	0,003617	Plage nomi-nale
0	0,000	
-1	-0,003617	Plage de dépasse-ment bas
-4864	-17,593	
-32768	<-17,593	Déborde-ment bas

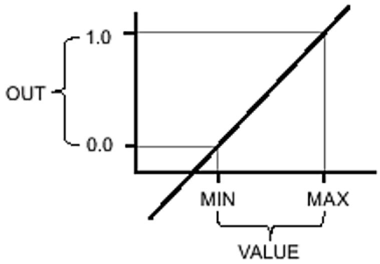
4.5 Normalization and Scaling of Analog Values Read by the PLC

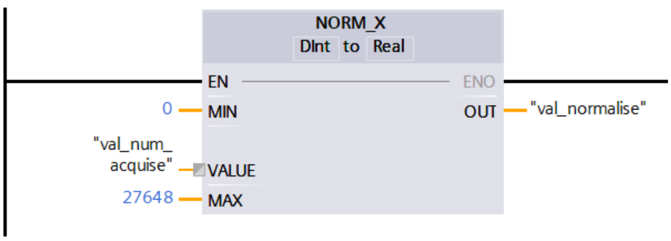
The analog values read by the PLC must be normalized and scaled before being processed by the user program. To achieve this, two instructions from the **Conversion** library are used.



a) NORM_X Instruction (Normalize)

This instruction is used to normalize the value of the input variable **VALUE** by mapping it to a linear scale. The parameters **MIN** and **MAX** define the limits of the value range, which is then reflected on the normalized scale.





Given that: 0 < VALUE < 27648

The "Normalize" instruction uses the following equation:

$$\mathbf{out} = \frac{\mathbf{value-min}}{\mathbf{max-min}} \quad , \quad 0 < out < 1$$

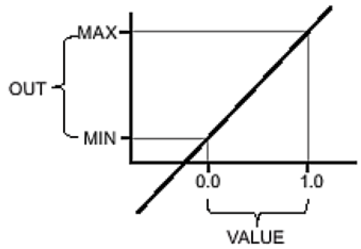
Example: Let us assume that the value acquired from the analog input IW64 is equal to 9000.

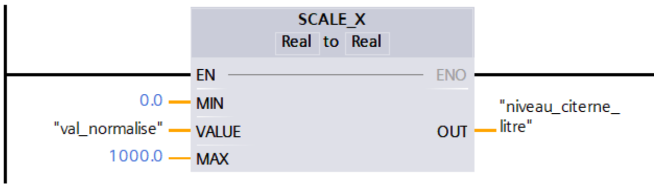
Value = val_num_acquise = 9000

then $\text{out} = \frac{9000-0}{27648-0} = 0{,}325$

b) SCALE_X Instruction (Scaling)

This instruction is used to scale the value at the input **VALUE** by mapping it to a specified value range. When the **Scale** instruction is executed, the floating-point number provided at the **VALUE** input is scaled to the range defined by the **MIN** and **MAX** parameters. The result of the scaling is an integer value that is stored in the output **OUT**.





The **'Scale'** instruction uses the following equation:

$$\mathbf{out} = \mathbf{value} \cdot (\mathbf{max} - \mathbf{min}) + \mathbf{min}$$

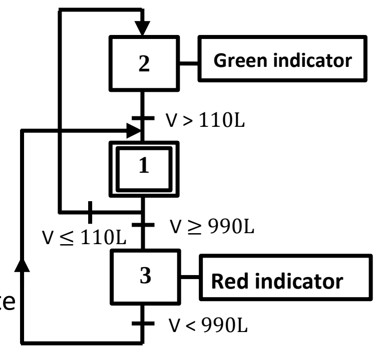
Example :

Value = val_normalise = 0,325

$$\text{Out} = 0{,}325 \cdot (1000 - 0) + 0 = 325 \text{ liters}$$

niveau_citerne_litre ← out

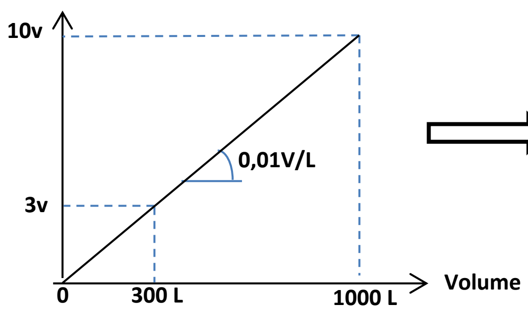
5 Application : contrôle de niveau d'eau dans une citerne (AI en tension)



To measure the water volume in a 1000-liter tank, a linear level sensor (see figure below) is used along with a Siemens PLC (CPU S7-1214C).

- If the water level in the tank is **≤ 110 liters**, the **green indicator light** turns on.
- If the water level is **≥ 990 liters**, the **red indicator light** turns on.

The filling of the tank is **not controlled by the PLC**; the PLC is used solely to indicate the water level.



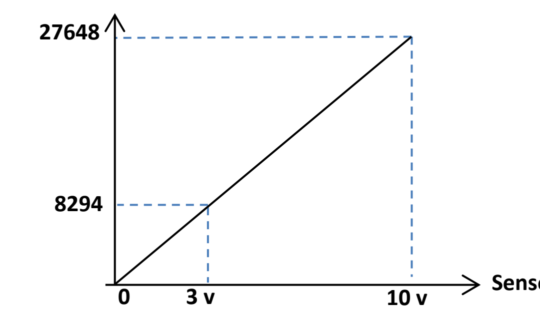


Figure 3. Characteristic curve of the level sensor **Figure 4.** Voltage converted into numeric values read by the PLC

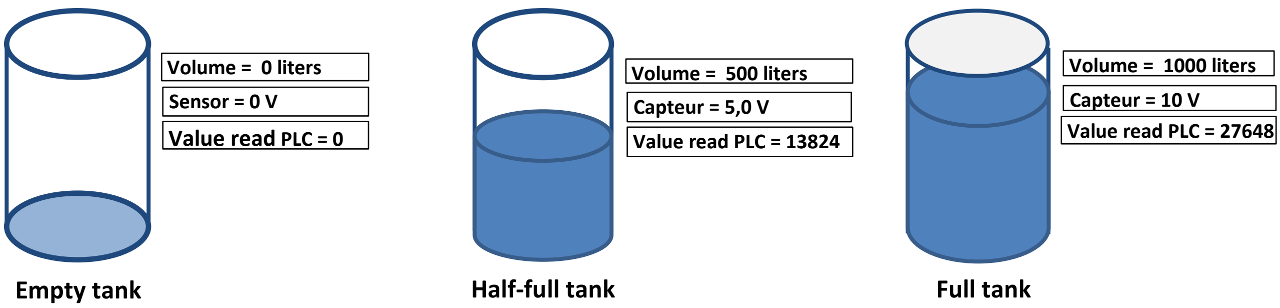


Figure 5. Correspondance entre le volume d'eau, tension délivrée le capteur et la valeur acquise par l'API.

The S7-1214C CPU includes 2 analog voltage inputs with a voltage range of 0 to 10 V.

The variation range of the water volume in the tank: **0L** ⟶ **1000L Volume**
The voltage output range of the sensor: **0V** ⟶ **10V Voltage**
The range of digitized values acquired by the PLC: **0** ⟶ **27648 Integer**

If the water level in the tank is 500 liters, the sensor delivers a voltage of 5 V. This voltage is then converted into a digital value by the PLC.
To determine the value acquired by the PLC, a proportional rule (rule of three) is applied.

$$\text{Value read by the PLC} = \frac{500 \times 27648}{1000} = 13824$$

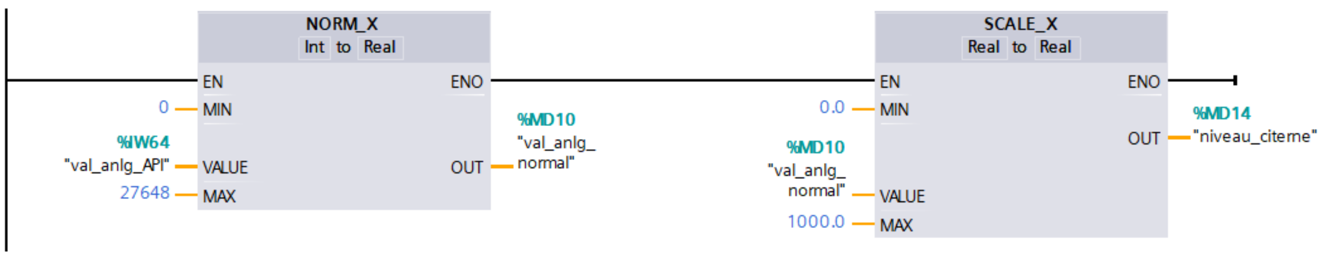
5.1 Programming the Application on the Siemens PLC

5.1.1 Program Variable Declaration

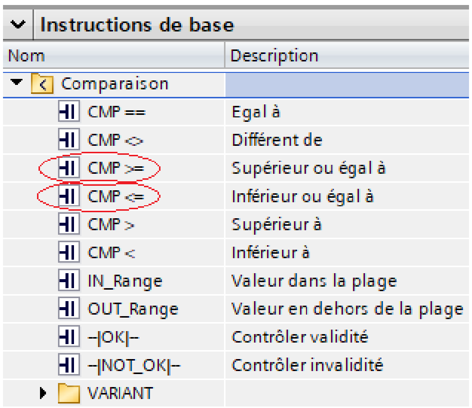
It is always necessary to start by declaring the program variables before proceeding with the programming itself.

Nom	Type de données	Adresse	Réma...	Visibl...	Acces...	Commentaire
voyant vert	Bool	%Q0.0	☐	☑	☑	si niveau <= 110 litres
val_anlg_API	Int	%IW64	☐	☑	☑	valeur acquise par l'API
voyant rouge	Bool	%Q0.1	☐	☑	☑	si niveau >= 990 litres
val_anlg_normal	Real	%MD10	☐	☑	☑	
niveau_citerne	Real	%MD14	☐	☑	☑	

5.1.2 Normalization and Scaling of the Analog Variable Acquired by the PLC (val_anlg_API)



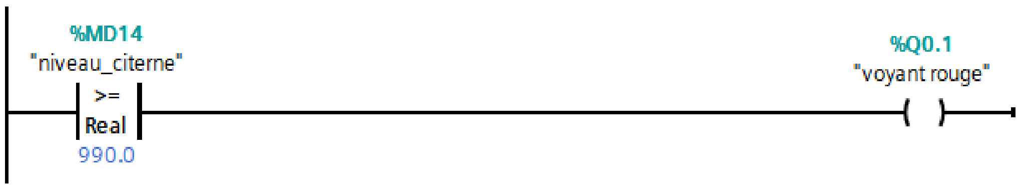
To test the tank level, comparison components (≥ and ≤) are used, represented by the symbols from the Comparison library (see figure below).



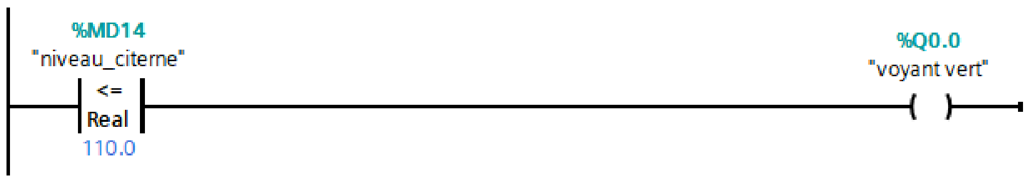
Instructions de base

Nom	Description
Comparaison	
CMP ==	Egal à
CMP <>	Différent de
CMP >=	Supérieur ou égal à
CMP <=	Inférieur ou égal à
CMP >	Supérieur à
CMP <	Inférieur à
IN_Range	Valeur dans la plage
OUT_Range	Valeur en dehors de la plage
-|OK|-	Contrôler validité
-|NOT_OK|-	Contrôler invalidité
VARIANT	

If the tank level is ≥ 990 liters



If the tank level is ≤ 110 liters



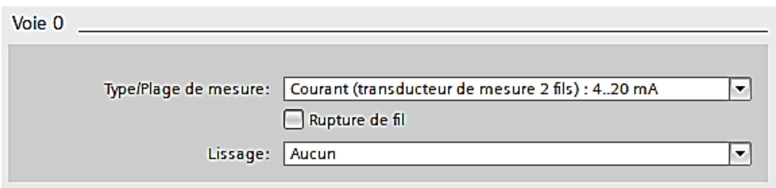
The figure below shows a simulation in TIA Portal V13 of the normalization and scaling of the analog input.

6 Application: Water Level Control in a Tank (Analog Input in Current Mode)

Le changement de niveau dans le réservoir est enregistré via un transmetteur de boucle de courant dans la boîte à bornes de l'indicateur de niveau et est converti en un **signal de courant 4-20 mA**.

The variation range of the water volume in the tank:	**0L**	$\longrightarrow$	**1000L**	**Voltage**
The current output range of the sensor:	**4mA**	$\longrightarrow$	**20mA**	**Currant**
The range of digitized values read by the PLC:	**0**	$\longrightarrow$	**27648**	**Integer**

Note: The analog input on the PLC must be configured to measure current variations within a range of 4 to 20 mA, which corresponds to a measurement span of **16 mA**.



Example

If the current delivered by the sensor is 9.56 mA, what will be the value read by the PLC, and what is the water volume in the tank?
To determine the digitized value read by the PLC, first subtract 4 mA from the sensor output to get the effective measured current. Then, apply the proportional rule (rule of three) to calculate the corresponding digital value and water volume.

$$\text{the value read by the PLC} = \frac{9{,}56 - 4}{(20 - 4)} \times 27648 = 9607$$

The current measurement range is 16 mA.

$$\text{the water volume in the tank} = \frac{9607}{27648} \times 1000 = 347 \text{ litres}$$