Instrumentation & Industrial Automation Final Project

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***Abstract*—In this project, it is deeply analyzed a level plant with all its components, systems and subsystems. Understanding its operation and proposing control techniques.**

I. Introduction

Level plants have been used throughout history for many applications, mainly industrial or water storage. The correct use of the level plants is by means of a controller, an actuator and their respective sensors that are constantly feeding back the system.

II. Artistic System's Drawing

The level plant is made up of two tanks, the upper tank is to receive the water from the pipe and begin its filling to generate the different level measurements; The bottom tank is the storage tank where all the fluid (water) is kept when the system is not working.

The level plant, is about a water reserve tank, the water leaves through a pipe to enter a centrifugal pump, this pump is in charge of the suction or the fluid impulse, it rises through the pipe passing through a flow sensor, it's called rotometer, it also passes through several ball valves, and a pressure gauge; then a fork is presented.

On one way the water crosses a solenoid valve, a ball valve, and from there it rushes to the tank. In the second way, the liquid passes through a globe valve, which is affected by a diaphragm with a positioner, which receives two signals, one pneumatic and one current, the purpose is to convert it into pressure; that pressure is in order to control the opening or closing of the globe valve, that is, to influence the flow of water passing through the pipe, at the end of the section is the last ball valve to reach the water tank.

In the tank there are 4 level switches, these send a signal to the control panel, by means of visual indicators (lights) the water level is appreciated. At the base of the tank there is an output with one ball valve, its task is to allow the water to drain from the main tank to the reserve tank. Also, on the bottom of the water tank, there is a pressure sensor connected to a pressure transmitter which is connected to the control panel to indicate the water level.

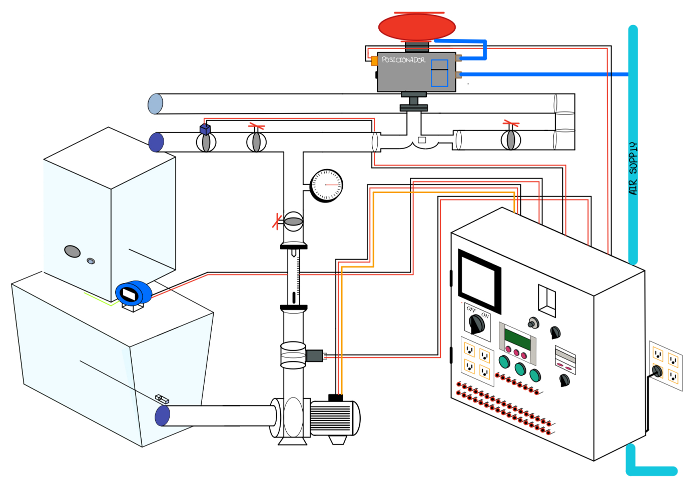

Figure 1: Artistic system´s drawing

<u>Tank</u>

As can be seen on figure 2 the upper tank has 3 floats-level switches, which send a binary signal to the controller once the water reaches that point.

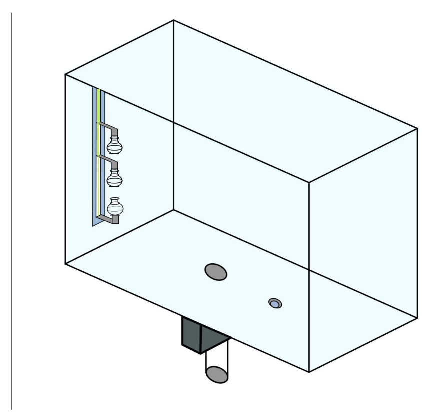

Figure 2: Upper tank artistic design

This lower tank is where the water is saved when the system isn't playing, and is where the water starts its tour through the pipe.

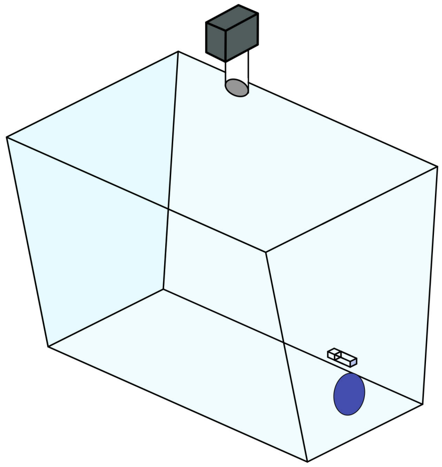

Figure 3: Inferior tank artistic design

Level switches: they are responsible for activating and sending a binary signal to the controller to activate light indicators depending on the amount of water in the tank.

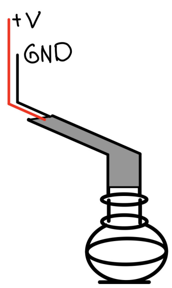

Figure 4: Level switches artistic design

Pump

Motor: according to its speed, it changes the force and the flow of the fluid coming from the lower tank.

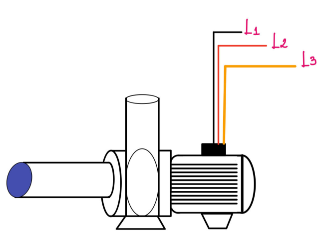

Figure 5: Motor artistic design

Variable frequency drive: according to an external signal from the controller with its own frequency, the motor speed changes by changing the frequency and voltage of the power supplied to the motor.

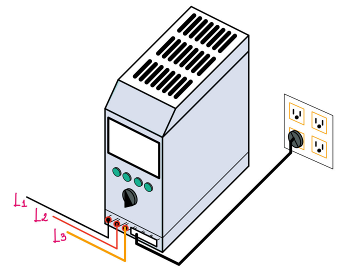

Figure 6: Variable frequency drive artistic design

Flow Transmitter

Power Supply: The power supply which powers the transmitter to be able to operate and measure the flow variables.

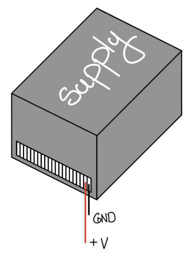

Figure 7: Variable frequency drive artistic design

Flow Sensor: takes the flow that passes through the pipe coming from the pump and converts it to an electrical signal.

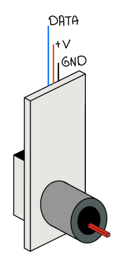

Figure 8: Flow sensor artistic design

Transmitter: Takes the electrical signal from the sensor and converts it to a standard electrical signal for transmission.

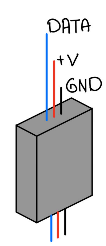

Figure 9: Transmitter artistic design

Conditioning circuit: this corrects the errors of the signal, whether it is zero, spam or both, and filters it, eliminating the noise and then sending it to the controller.

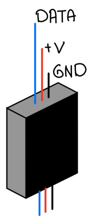

Figure 10: Conditioning circuit artistic design

Level transmitter

Unlike other level measurement technologies, the pressure sensor protects against false measurements with changes in viscosity or contaminants in the water.
To know the level using pressure sensors it is very important to know the hydrostatic pressure formula.

$$P_{hydrostatic} = \rho \times g \times h$$

Where:

- P is the hydrostatic pressure
- ρ is the density of the fluid system
- g is the gravity
- h is the height(level) of water inside the tank

And also the atmospheric pressure which is the environment pressure, or better knnown as the air column above each person or object.
It also must be known the fluid density, in this case for this project it's going to be worked with the water as the system's fluid. Therefore, according to that statement.

$$\rho = 997kg/m^3$$

$$\rho \approx 1000kg/m^3$$

The sensor will be in charge of delivering some voltage signal according to the hydrostatic pressure it feels upon the tank.
Knowing the gravity, the fluid density and the pressure thanks to the sensor, it can be found the height or level of water in the tank.

$$h = \frac{\rho \times g}{P}$$

How the tank is exposed to the air, it must have in account the atmospheric pressure. So the absolute pressure the sensor may find has to be subtracted.

$$P_{final} = \rho \times g \times h - P_{atmospheric}$$

Due to this, the pressure transmitter works with a differential pressure, this because it can measure 2 type of pressures.
The first one P1 is measured at the base of the main tank, so:

$$P_1 = \rho \times g \times h + P_{atmospheric}$$

And the second one is:

$$P_2 = P_{atmospheric}$$

To finally find the pressure is wanted, which is only de hydrostatic pressure, it's done a $\triangle P$.

$$\triangle P = P_1 - P_2 = P_{final} = \rho \times g \times h$$

Power Supply: The power supply which powers the transmitter to be able to operate and measure the level variables.

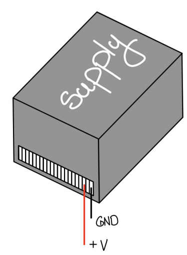

Figure 11: Power supply artistic design

Pressure sensor: This sensor is the one that measures the pressure exerted on the base of the tank, since this level transmitter obtains this variable by identifying the pressure variation in the system.

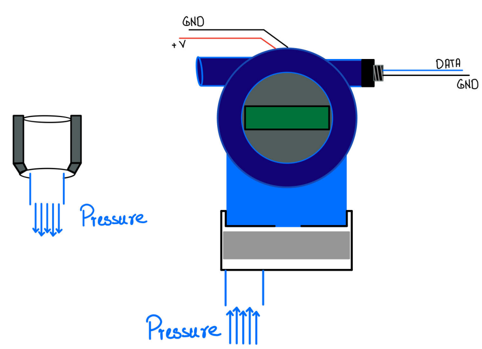

Figure 12: Pressure sensor artistic design

Transmitter : Takes the electrical signal from the sensor and converts it to a standard electrical signal for transmission. It is in charge of converting the pressure variables to issue standard current and voltage values.

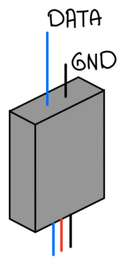

Figure 13: Transmitter artistic design

Conditioning circuit: This filters the signal measurements of any type of noise or external inconvenience to send it properly to the controller.

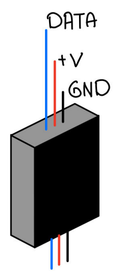

Figure 14: Conditioning circuit artistic design

Diaphragm valve

This device is responsible for partially stopping or closing, it means, regulating the circulation of the fluid(usually in this case, water) by means of a diaphragm that serves as a shutter. This would be usually set at the end of the piping system before the fluid is deposited in the tank.

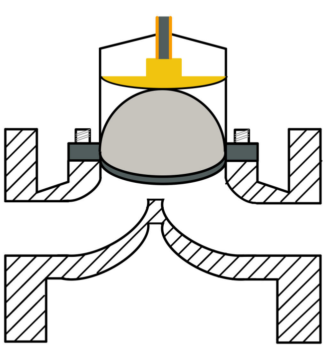

Figure 15: Bellow type globe valve artistic design

Positioner: This is in charge of positioning the valve stem for when it doesn't present the pressure applied for its movement, and provides accuracy when it comes to regulating fluid circulation.

The gauge: this component is in order to measure system pressure, is a manual pressure gauge, and doesn't send any electrical signal to the controller.

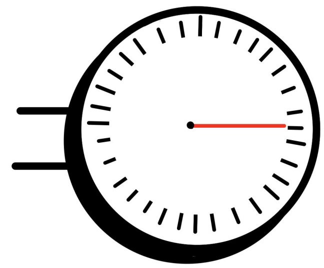

Figure 16: Gauge artistic design

Ball valves

It is a simple and relatively cheap valve that regulates the flow of the system. Its regulating mechanism located inside is shaped like a sphere.

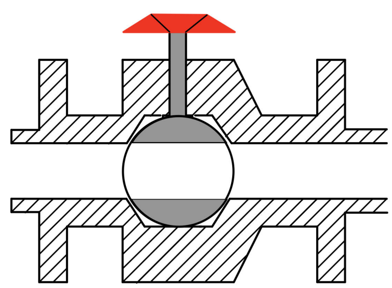

Figure 17: Ball valve artistic design

Controller

The controller receives signal from the pressure transmitter, the level sensors and the flow transmitter.
The control panel has indicator lights for the level at which the water in the tank is located. It has 4 lights, one for very low level, low level, high level and very high level.
The controller is composed of 4 subsystems.
The power supply: This provides the power signal to the controller so that it can work.

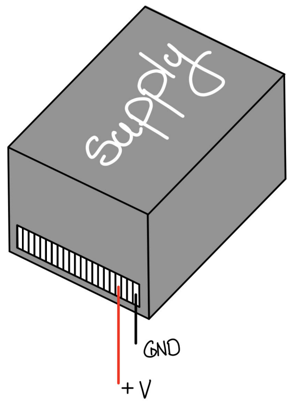

Figure 18: Supply artistic design

Analog to Digital Converter (ADC): This as the name says, is responsible for converting the analog signals emitted by the sensors or transmitters and converting them into a binary signal to be interpreted.
The processor: This is the place where signal processing is programmed and instructions for making decisions and output signals are indicated to the controller.
The processor is the subsystem that keeps the instructions from the memory and the signals from the sensors and transmitters, and then through it, provide an output to the system.
Light indicators: These are intended to visually indicate to the operator at what level the amount of water is in the tank. Those 4 lights are one for very low level, low level, high level and very high level.

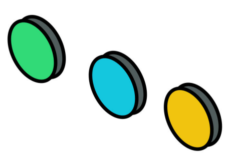

Figure 19: Light indicators artistic design

III. Black box subsystems

A. Actuator subsystem

Motor:

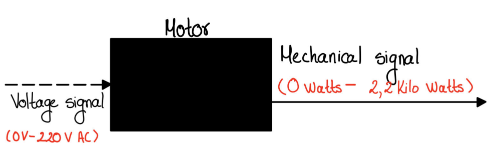

Figure 20: Motor black box diagram

Variable frequency drive:
An AC voltage signal enters the frequency changer, which goes through a process of conversion to DC voltage to be able to change the frequency of the system, then once the frequency change has been made, the signal changes again to alternating current. Therefore, at the output, it will have a different frequency within a range from 0Hz to 60Hz from the system and its AC voltage signal.

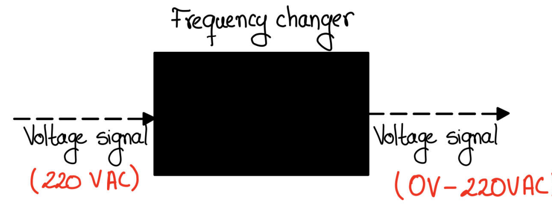

Figure 21: Frequency changer black box diagram

B. Flow transmitter

Sensor:
The flow sensor has a maximum capacity of 250 liters/minute, and as is known, $1m^3 = 1000L$.

$$250L/min \times \frac{1m^3}{1000L} = 0.25m^3/min$$

The sensor at the output releases a voltage signal from 2mV to 10mV according to the flow it was measured.

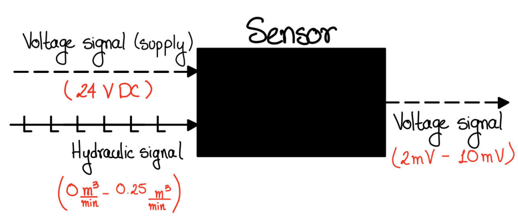

Figure 22: Sensor black box diagram

Transmitter: The transmitter for the flow has an input range from 2mV to 10mV and this is responsible for converting the signal into a standardized signal to have an output with a range from 0V to 5V.

Figure 23: Transmitter black box diagram

Conditioning circuit: The conditioning circuit has an input with a range of 4mA to 20mA, it is in charge of transforming that signal into a voltage signal, regulating the voltage to ensure a minimum value of 0V and a maximum of 5V, and in turn filtering any noise it may have.

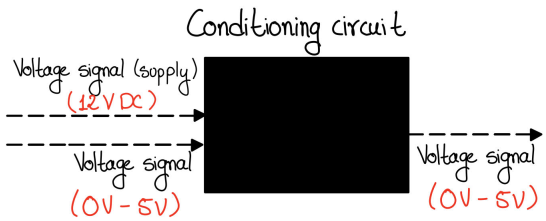

Figure 24: Conditioning circuit black box diagram

C. Pressure transmitter

Power supply: This power supply comes from a connection to a DC source of so many volts, and this signal is sent to the sensor system device so that it can work. That voltage signal has a range from 0V to 24V.

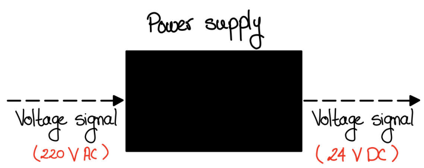

Figure 25: Supply box diagram

Pressure sensor: A pressure signal enters with a minimum value of -62.2mBar to 62,2mBar, and this sensor is in charge of realising a range of voltage from 10mV to 15mV, according to the pressure was measured by that sensor.

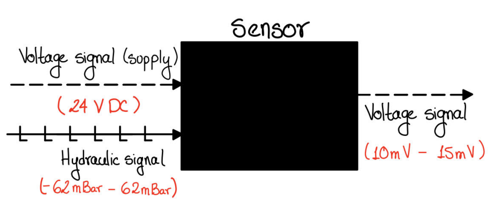

Figure 26: Pressure black box diagram

Transmitter: This subsection receives the output signal form the sensor and it converts it into a standardized signal with a range from 4mA to 20mA, which is going to be the output according to that input voltage signal. In experimental tests it was found that this output range is actually between 4.7 to 15mA.

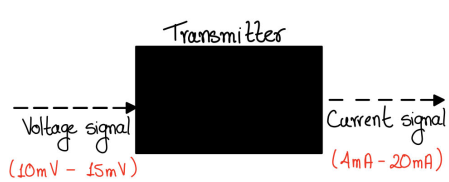

Figure 27: Transmitter black box diagram

Conditioning circuit: The conditioning circuit has an input with a range of 4mA to 20mA, it is in charge of transforming that signal into a voltage signal, regulating the voltage to ensure a minimum value of 0V and a maximum of 5V, and in turn filtering any noise it may have.

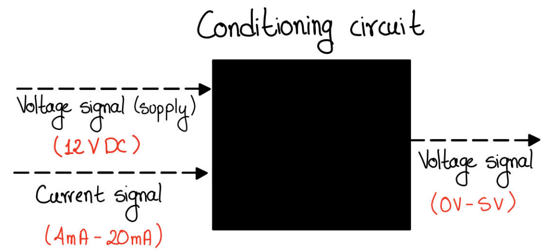

Figure 28: Conditioning circuit black box diagram

D. Level switches

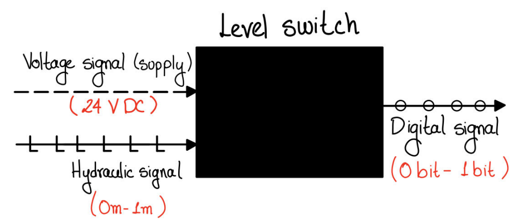

Figure 29: Level switches black box diagram

E. Controller

Power Supply:

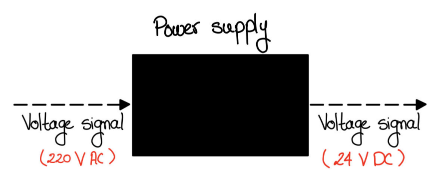

Figure 30: Supply box diagram

ADC Analog-Digital Converter

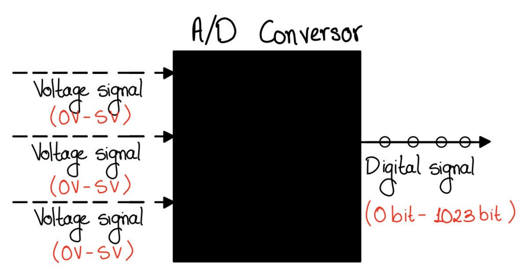

Figure 31: ADC box diagram

Processor

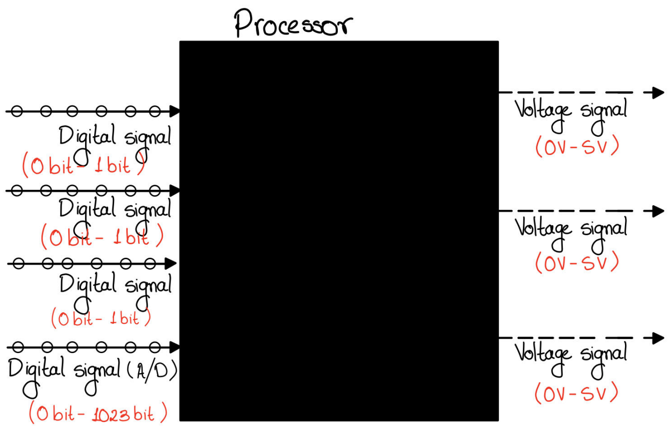

Figure 32: Processor box diagram

Table I: Signal value and type

Signal	Type	Units
Motor input signal	Electric	Volts
Motor output signal	Mechanic	kW
Frequency changer input signal	Electric	Volts
Frequency changer output signal	Electric	Volts
Flow sensor input signal	Hydraulic	m^3/s
Flow sensor output signal	Electric	Volts
Flow transmitter input signal	Electric	Volts
Flow transmitter output signal	Electric	Volts
Flow conditioning circuit input	Electric	Volts
Flow conditioning circuit output	Electric	Volts
Flow Power supply input	Electric	Volts
Flow Power supply output	Electric	Volts
Flow conditioning circuit input	Electric	Volts
Flow conditioning circuit output	Electric	Volts
Pressure Power supply input	Electric	Volts
Pressure Power supply output	Electric	Volts
Pressure sensor input	Hydraulic	mBar
Pressure sensor output	Electric	Volts
Pressure transmitter input	Electric	Volts
Pressure transmitter output	Electric	mA
Pressure conditioning circuit input	Electric	mA
Pressure conditioning circuit output	Electric	Volts
Level switches input	Hydraulic	m
Level switches output	Digital	bits
Controller Power supply input	Electric	Volts
Controller Power supply output	Electric	Volts
Controller ADC input	Electric(analogical)	Volts
Controller ADC output	Digital	bits
Controller Processor input1	Digital	bits
Controller Processor input2	Digital	bits
Controller Processor input3	Electric	Volts
Controller Processor output	Electric	Volts

IV. Block diagram

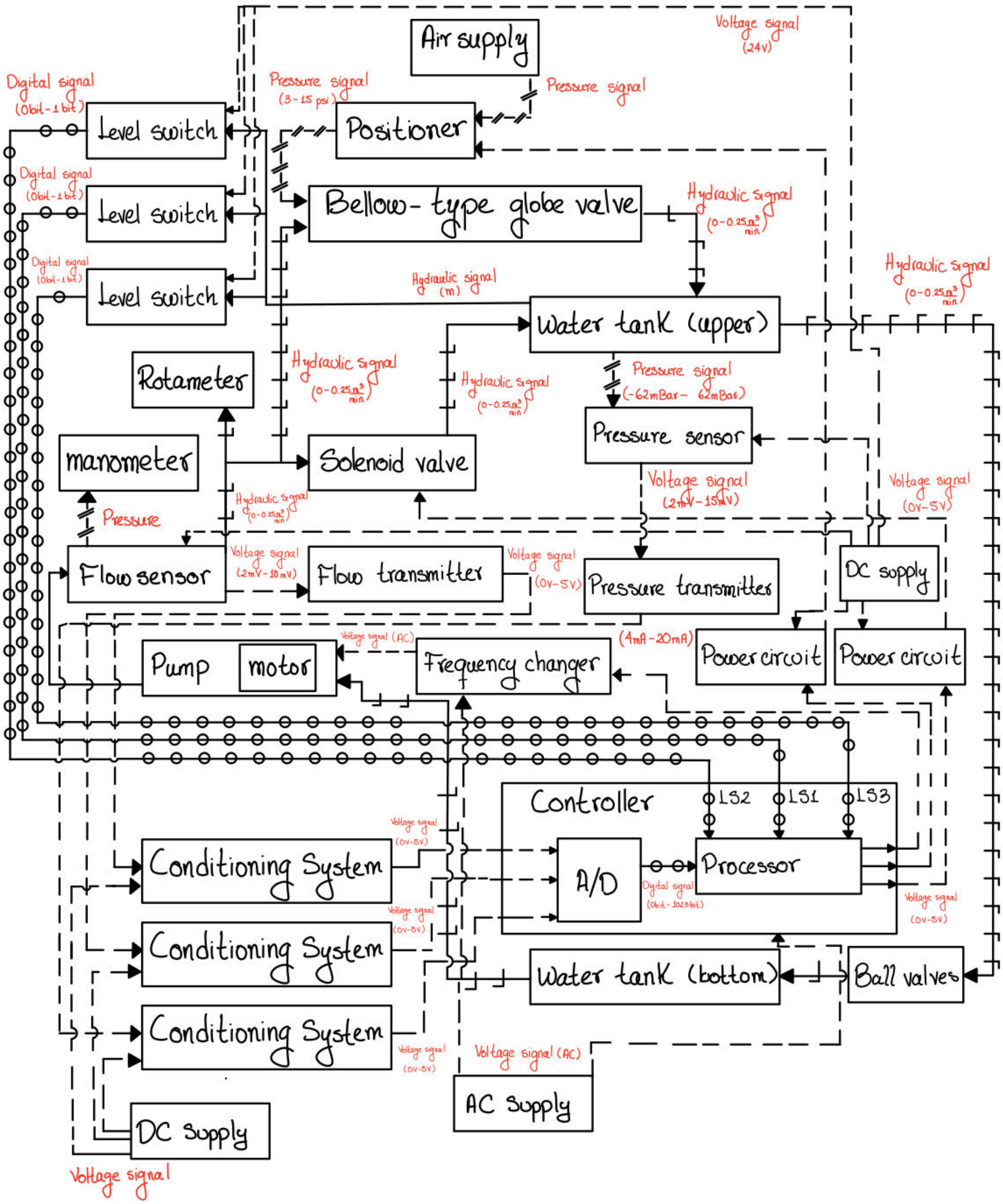

Figure 33: Block diagram

V. Commercial components

A. Flow sensor

The flow sensor is a complementary sensor that is available for the level plant, however, the fundamental sensor for this plant is the pressure sensor, because thanks to this it is possible to identify and control the water level of the system. Despite that, here are some commercial flow sensors that can be applied to the system.

MAG-VIEW 250-Q
This MAG-VIEW flow sensor offers an economic and also with high quality flow measurements. This product has a long-life cycle and a wide independence to the inlet and outlet pipes. This gives the possibility for measuring flow in areas where flow sensors with moving parts can't be applied.[14]

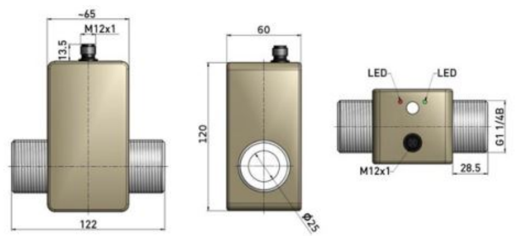

Figure 34: 250-Q Mechanical design.Taken from MAG-VIEW's datasheets

MAG-VIEW 260-P
Mostly this sensor, unlike the 250-Q, has a much smaller flow operating range, which leads to a lower flow; however, when is wanted a large flow through the pipe, it will not have that possibility.

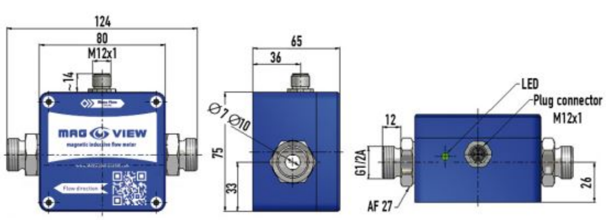

Figure 35: MAG-VIEW 260-P Mechanical design. Taken from MAG-VIEW's datasheets

ESK3x DK34
This flow transmitter is very useful for measuring very small quantities of flow, it can be used for air, water, gases and other types of substances. There may be potential difficulties with this one in ensuring electromagnetic compatibility in other environments different from industrial ones, due to conducted as well as radiated disturbances. The ESK3x electrical signal output is configured via HART communication. [9]

Figure 36: ESK3x DK34 design. Taken from KROHNE's datasheets

Here's the schematic drawing for this DK34.

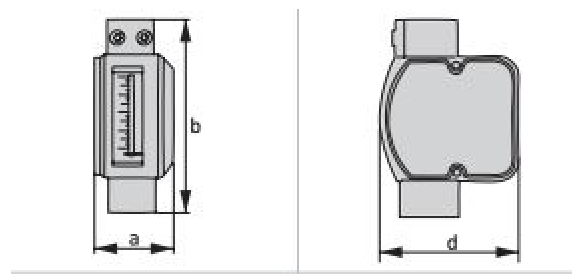

Figure 37: ESK3x DK34 schematic design. Taken from KROHNE's datasheets

Table II: Flow sensor component comparisons

	MVM-250Q	MVM 260-P	ESK3x DK34
Operation range	5 L/min - 250 L/min	1 l/min - 60 l/min	12l/min - 90l/min
Supply voltages	24V CD ±10%	24V CD ±10%	12V - 32V DC
E. consumption	0.7 W	3.6W	4.4W
Comm. interface	SPS/PLC	PLC	Hart
Price	EUR$710	EUR$536	EUR$678

According to this analysis, the transmitter was decided the MVM-250Q because it can work with much higher flows and this allows the plant to fill up quickly and still be measured and monitored by its respective flow transmitter. Furthermore, this reference guarantees a very good quality for the measurement. Its energy consumption is not so high and it has a good communication interface because PLC controllers are the most common to work with and the most information is available. The MVM 250Q is chosen, since the energy consumption is the lowest, and despite having a much higher price than the others, this price recovers with the little energy consumption it has. Additionally, MAG VIEW is a recognized brand and features a wide range of flow options.

B. Pressure sensor

The pressure sensor is the main sensor of the system, thanks to this and its respective transmitter, the level of the plant can be identified and through this, information is sent to the controller so that it is in the capacities to monitor and manipulate said level.
3 different references were found for this pressure sensor

and transmitter. Below are the characteristics, advantages and disadvantages of each of them.

WIKA A-10

The Model A-10 Pressure Transmitter for Applications general industrial stands out not only for its design compact but also for its excellent quality at a price very economical[16].

Figure 38: A10 schematic design. Taken from WIKA's datasheets

Differential pressure DS200

This kind of sensor is very similar to the other ones, however it keeps some differences, for example its design. The brand Arthur Grillo offers some own characteristics like the MENSIO measuring system, it also works with a particular alarm and a software menu for parameterization[12].

Figure 39: DS200 design. Taken from Arthur Grillo's datasheets

Differential PMP manometer

This manometer focuses on the differential pressure control in gases or non-corrosive gases. The brand of this manometer is KOBOLD.

The indication of the pressure difference is made by 4 LEDs. The equipment is equipped with a microprocessor that makes easier its programming[13].

Figure 40: DS200 design. Taken from Kobold's datasheets

Table III: Pressure sensor component comparisons

	WIKA A-10	DS200	PMP manometer
Operation range	0-1Bar	0-60mBar	0-50mBar
Supply voltages	8V-30V	17V-30VDC	24VDC
Energy consumption	1W	0.6W	4W
Price	EUR $134, 55	US $318	US $270

The DS200 is chosen because it is good that the pump is differential pressure, unlike the A-10 which is absolute pressure. Also, it has good ranges of supply voltage. Unlike the A-10, the DS200 has enough ranges for the system which are 60mBar.

On the other hand, energy consumption is less.

C. Controller

The controller is very important for the system, it is in charge of receiving the information from both the flow and pressure sensors to process said data and send orders according to said variables. It also sends commands to the solenoid valve and the possible positioner, in case the latter is mounted in the system.

Neto Xpress BCS-XP300

This controller has a compact design, it has analog inputs, it has a high-speed 32-bit ARM-based processor. It also has included a very interesting component which is a compact PLC module. [1]

Figure 41: BCS-XP300 design. Taken from Beijer electronic's datasheets

FATEK FBS-10MCJ2-AC
Some of its functions is ADCNV which is in order to convert the analog inputs to digital signals, or CMP which is for comparing some values.The brand of this controller is very recognised and this component has a lot of functions and characteristic which allow it to make or work more in other things that aren't required but that make the plant a better and completer system.

Figure 42: FBS-10MCJ2-AC design. Taken from FATEK's datasheets

Controllino MAXI AUTOMATION
Controllino is an Arduino standard and Arduino software compatible PLC. It works with SPI (Serial Peripherial Interface) is an interface bus commonly used to send data between microcontrollers and small peripherals such as shift registers, sensors, etc.

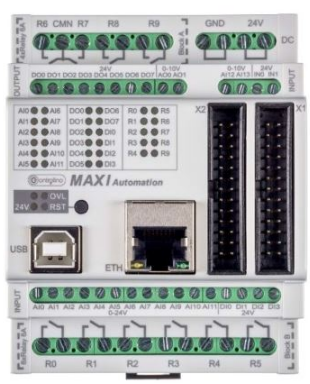

Figure 43: Controllino design. Taken from MAXI AUTOMATION's datasheets [3]

Table IV: Controller component comparisons

	BCS-XP325	FBS-10MCJ2	Controllino
Inputs	5 Multipurpose analog inputs	Mostly digital inputs	2x10V Analog inputs
Supply voltages	19.2V-30V	24V $\pm 20\%$	24V
E. consumption	5W	21W	NF
Comm. interface	Can-PLC	PLC-enthernet	SPI
Temp. Operation	0ºC-60ºC	5ºC-55ºC	0ºC-55ºC
Weight	430g	NF	240g
Price	USD$230.18	USD$148.50	USD$292.99

The best controller among the options mentioned above, is the BCS-XP325 because despite not being as complete as FBS-10MCJ2 it satisfies the needs of the level plant system, also because it has a great focus on the analog inputs that It is something that is very much needed in the system, it also has a relatively light weight and the price is favorable and similar to the others. The power being 5W is good and does not use much energy. On the other hand it has a good communication interface.

D. Pump-Actuator

Hasa NIZA 10.6T pump
This one is a very silent multicellular centrifugal electric pumps ideal for small domestic lobbyists, single-family homes and sprinkler irrigation. Its motor is closed with external ventilation.[15]

Figure 44: NIZA 10.6T design. Taken from hasa's datasheets

FL20C Centrifugal pump
The FL20C centrifugal pump is characterized by its compact size and high performance. These pumps can be used in low viscous fluid transfer applications such as water, oils, glycols and wines[10].

Figure 45: FL20C design. Taken from fluid MIM's datasheets

Bredel 40 pump
This pump is designed with a suction height capacity of up to 9.5 meters. It has a solid design resistant to aggressive chemicals and abrasives.[2]

Figure 46: Bredel 40 design. Taken from Bredel's datasheets

Table V: Pump comparisons

	NIZA 10.6T	FL20C	Bredel 40
Power required	2.8kW	0.37kW	3kW
Supply voltages	19.2V-30V	24V ±20%	24V
Flow	10600l/h	12000l/h	9600l/h
Price	EU$523	NF	NF

The FL20C pump was chosen as the pump for the level plant system, because it has a much smaller consumption and gives a very large flow, the flow is necessary for a good flow of water. On the other hand, it can work in the 20% 24V range, which makes it more flexible. Also the characteristics of the datasheet for said pump make it the ideal pump for this type of system.

E. Variable frequency drive

VACON®20

Figure 47: VACON0020-3L-0004-2-CP design. Taken from vacon®20 CP datasheets [11]

The VACON®20 series has a quality that at currents higher than 16A, has an integrated inductance to filter the harmonics of the public networks in accordance with the standard IEC61000-3-12 [7]. Thanks to its optional modules, VACON® 20 can be connected to virtually any fieldbus including CANOpen, DeviceNet and PROFIBUS DP. Also it allows you to modify with total freedom the list of parameters, as well how to create specific default settings and parameter sets for the application.

For this case we thought that an appropriate model would be the VACON0020-3L-0004-2-CP [**VF˙3.1**]

Table VI: Characteristic of VACON0020-3L-0004-2-CP

	VACON0020-3L-0004-2-CP
Operation range	0Hz - 320Hz
Supply voltage	208V - 240V ±10%
Communication interface	RS-485/PLC
Price	3'100.00

VLT® Midi Drive FC 280

Figure 48: VLT® Midi Drive FC 280 design. Design Guide [5]

It has a strong control performance, functional safety and communication flexible field bus system, RFI filter, functional safety Dual channel STO. The VLT Midi Drive is designed to operate at a temperature 45 °C ambient temperature at full load, and 55 °C with reduction of power, for this, it is not necessary to install a additional cooling equipment or over-dimension the converter of frequency[6]. For configuration, the FC 280 presents VLT® Motion software Danfoss Control Tool MCT 10. This tool provides the plant managers an overview complete system in any time and a high level of flexibility. Communicate using the process automation system:

- PROFINET with dual port
- POWERLINK with dual port
- EtherNet/IP™ with dual port
- PROFIBUS
- CANopen
- Modbus RTU and FC protocol integrated as standard

Table VII: Characteristic of VLT® Midi Drive FC 280

	Midi Drive FC 280
Operation range	0Hz - 500Hz
Supply voltage	208V - 240V ±10%
Communication interface	RS-485/PLC
Price	2'000.000 COP

VLT® Micro Drive FC 51

Figure 49: VLT® Micro Drive FC 51 design. Taken from VLT® Design Guide [4]

Simple and fast installing, bringing 5 programmable digital inputs, 1 analog input (0-10 V) or (0 - 20 mA), an DC-bus RS45 [8] . Electromagnetic disturbances of the motor cables are controlled by the built-in RFI filter in the unit, allowing for lengths of motor cable (shielded) to 15 m, due to its efficiency of 98% the power lost are very low, for this, the overheating is not a great issue, a efficient temperature control allows the device to work in situations of room temperature up to 50° C. Field bus communication:

- Protocol FC.
- Modbus RTU

Table VIII: Characteristic of VLT® Micro Drive FC 51

	VLT® Micro Drive FC 51
Operation range	0Hz - 200Hz
Supply voltage	200V - 240V $\pm 10\%$
Communication interface	RS-485
Price	901.575 COP

Now the question is, which one to choose?, for this case, we don't need to be rigorous, this because a very high frequency would be inefficient for the whole system, it could cause overheat problems in the future and increase the energy expenditure. For this reason we are going to choose the VLT® Micro Drive FC 51, because it has a great efficiency, enough output frequency for the system. Also, there is a feature of the driver, and it is special mode that lets the output frequency increment 200Hz, this an output frequency of 0Hz to 400Hz

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