A Smart Automation System for the Management and Control of a Medium Scale Digester Plant

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Abstract	The paper describes the implementation of control logic for the management of a medium-scale digester plant through a smart automation system. Such a digester was developed to produce biogas and biomethane subsequently to anaerobic digestion of agri-food wastes, with a particular interest in olive mill by-products. Temperature and pH are the main parameters that control the prototype's running and automatism. The plant is fed with two matrices having respectively acid (in the case of olive mill wastewater) and alkaline pH (i.e. livestock manure), thanks to which, substrate pH value is set. The temperature control is ensured by a couple of armoured heater elements, while cooling, can occur thanks to a water main directly connected to the digestor. The control logic is implemented for maintaining the temperature and pH values within a certain range to guarantee the optimal process parameters. The smart automation system consists of three PLC units, which manage the sensors to acquire temperature and pH data for process control and pressure and flow sensors to determine biogas production. A remote control interface was designed to allow manual or automatic control of the plant. The interface enables to navigate between four different windows: manual control, automatic control, parameter setting and trends, which shows the real-time measurements provided by the sensors. Furthermore, the interface allows for setting process parameters, controlling process progress and saving data history.

Keywords (separated by '-')	Automation system - Biogas plant - By-product smart use - ICT - Sensors

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Luigi Scarcello, Souraya Benalia, Giuseppe Zimbalatti, Antonio Fazari, and Bruno Bernardi

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1 Introduction

The war in Ukraine is speeding Europe's pivot toward renewable energies. In this context, biomass anaerobic digestion for biogas and biomethane becomes an attractive energy production source because of its environmental advantages [1, 2], which led the European Commission to propose ramping up biomethane production to 35 billion cubic metres by 2030.

In anaerobic digestion process, various types of biomass and organic wastes are converted into biogas using several types of plants. However, the process instabilities in the reactors, because of biomass properties, limit the expansion of facilities to high loading rates. The irregularities in the process can be addressed directly by altering the feedstock characteristics if a robust, and sensitive monitoring device is available [3]. Several offline methods were proposed to monitor anaerobic digestion process, from gas chromatography to mid-infrared spectroscopy, but they are expensive and time-consuming [4, 5]. Bio-electrochemical systems are an alternative for the online monitoring of these processes [6], but still, need improvements. On the other hand, among the online monitoring systems, Cruz et al. [7] constructed an automated system capable of monitoring some indicators of the anaerobic digestion process using the platform Arduino; while Bernardi et al. [8] developed a medium-scale plant based on a programmable logic controllers (PLC), which is more efficient to use in industrial processes. This latter was realised with the scope to improve methane production starting from the combination of olive mill wastewater (matrix A) and livestock manure (matrix B). To allow optimal production conditions, a control logic is implemented to maintain the temperature and pH of the global mixture obtained from the union of matrices A and B, within a certain operating range. This research reports how logic and interface controllers, for the acquisition and management of several inputs and outputs, were developed.

2 Medium-Scale Digester Plant Controllers

2.1 Smart Automation System

The automation system consists of several ABB PLC, in particular a unit AC500-ETH, a unit DC562 and two units AX561, which manage actuators and sensors according to process parameters, i.e., substrate temperature and pH. In addition, they enable to acquire, thanks to appropriate sensors, biogas properties in terms of temperature, pressure and flow, permitting therefore to quantify biogas production. Automation Builder 2.2.5 software was used as programming domain. The first step was to declare all the PLC units and then define the interface of communication. In our case, we used COM1 and ETH1 interfaces; this latter allows us to interact with the automation system by using a proper web server. Figure 1 shows the device window of the AC500-ETH unit.

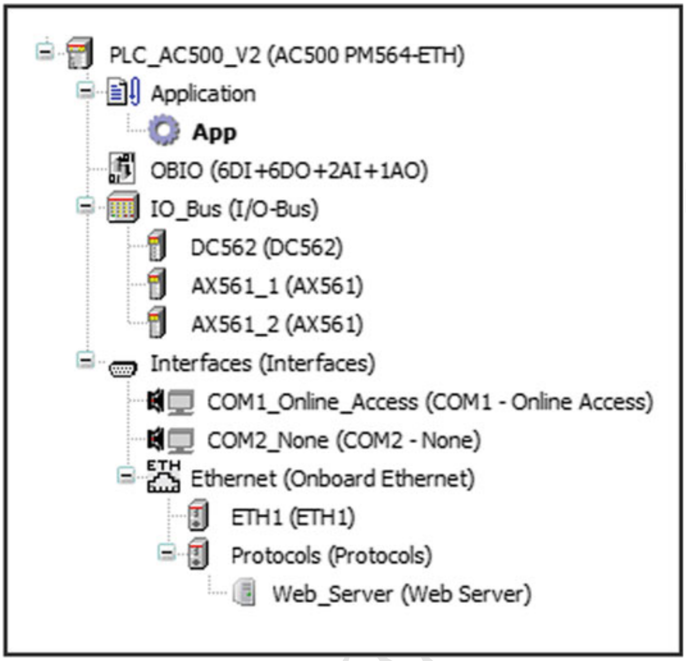

Fig. 1 Device window of the AC500-ETH unit

Communication with PLC units takes place physically via an RJ45 Ethernet cable, which connects the automation system to the notebook used to run the programming software. The use of the Ethernet protocol allows opening the control interface linked to the PLC through any client connected to the same LAN. In particular, the web server provided by the PLC that contains the control interface is invoked using a specific link.

The prototype's running and automatism depend on the following sensors: a temperature probe (placed inside the digester to measure the whole substrate temperature); a pH meter (placed inside the digester to measure the pH of the whole substrate); a pressure meter (placed at the outlet of the digester to measure the pressure of the biogas); and two flow meters (placed at the exit of the digester to measure the flow rate of biogas). While, actuators concern a suction pump (to feed the digester); a mixer (placed inside the digester to mix and favour substrate homogeneity); three solenoid valves (to control the matrices flows and water flow in case of cooling needs); two electrical resistors (to heat the substrate).

2.2 Control Logic

The implemented control logic is based on the acquisition and control of the following input and output signals, which can be analogical or digital. Table 1 reports the variables associated with the analogical/digital signals received or emitted by the automation system (the terminals correspond to the physical ports present on the AC500 and AX561 PLCs).

The programming language required by the automation system is based on the use of functional blocks, through which the system allows the acquisition of the analogical signals provided by the temperature, pH, pressure and flow sensors and properly manages the corresponding actuators (Fig. .2). The flowchart of the control strategy is shown in Table 1.

The plant is fed, using an electric pump, with two matrices having respectively acid (in the case of olive mill wastewater) and alkaline pH (i.e. livestock manure), until reaching the optimum pH value (around 7). The temperature control is ensured by a couple of armoured heater elements, while cooling, can occur thanks to a water main directly connected to the digestor, when temperature goes beyond T_{max}. The water flow rate is controlled by a solenoid valve.

Table 1 Input and output signals

Variable name	Type of signal	Type	Terminal
pH_{in}	Analog input AI0	INT	8
$Temperature_{in}$	Analog input AI1	INT	9
$Pump_{out}$	Digital output DO0/NO0	BOOL	13
$Mixer_{out}$	Digital output DO1/NO1	BOOL	14
$Resistors_{out}$	Digital output DO2/NO2	BOOL	15
$MatrixA_{out}$	Digital output DO3/NO3	BOOL	16
$MatrixB_{out}$	Digital output DO4/NO4	BOOL	17
$HeatingWater_{out}$	Digital output DO5/NO5	BOOL	18
$GasFlowRate1_{in}$	Analog input I0+	INT	2
$GasFlowRate2_{in}$	Analog input I1+	INT	5
$GasPressure_{in}$	Analog input I2+	INT	8

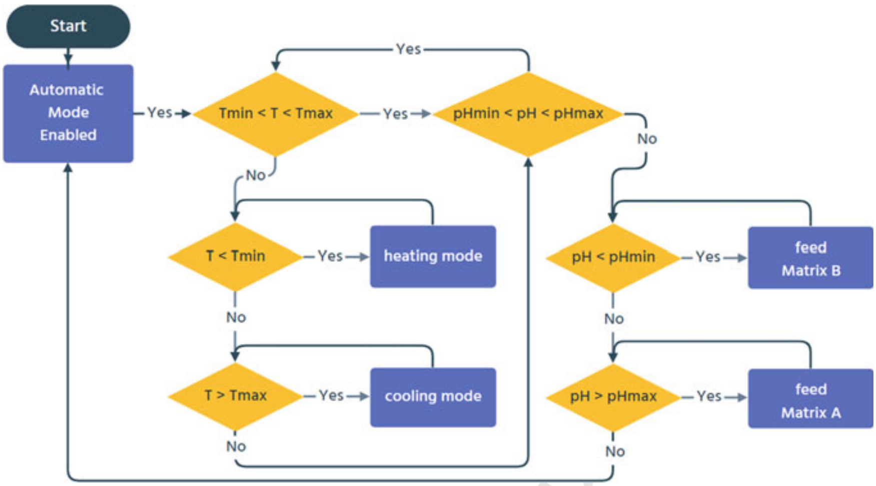

Fig. 2 Flowchart of the control strategy

2.3 Graphical Control Interface

The control interface, based on a smart interface, was designed to allow the user to control both manually and automatically the actuators, i.e. feed aspiration through an electric pump and respective solenoid valves, the mixer, the solenoid valve for the aspiration of cooling water and the two armoured heater elements.

Furthermore, it allows setting process parameters, controlling process progress, and saving data history. The interface enables to navigate between four different windows: manual control, automatic control, parameter setting and trends, which shows the progress of the measurements provided by the sensors in real-time.

Manual Control Mode

Figure 3 shows the manual control window. The display reports the biogas pressure and the gas flow rates measured by the two flow switches (left side), allowing to start and reset a timer for counting the days, hours, minutes, and seconds. The temperature and the pH of the substrate are displayed on the right side. Some lights (high and low) come on if the previous values exceed the maximum values or fall below the minimum values. By clicking on the grey buttons, certain actions are performed (after the activation, the active button changes colour).

For example, by clicking on the "CARICA A" button, matrix A is loaded. The operation is performed at a time interval of 10 s. This range can be changed by dragging the corresponding selection bar. At the bottom, status lights are displayed to provide the real-time status of the actuators (red colour indicates off, green colour indicates on). It is possible to change the window and choose the working mode by clicking on the type control buttons placed at the bottom of the control interface.

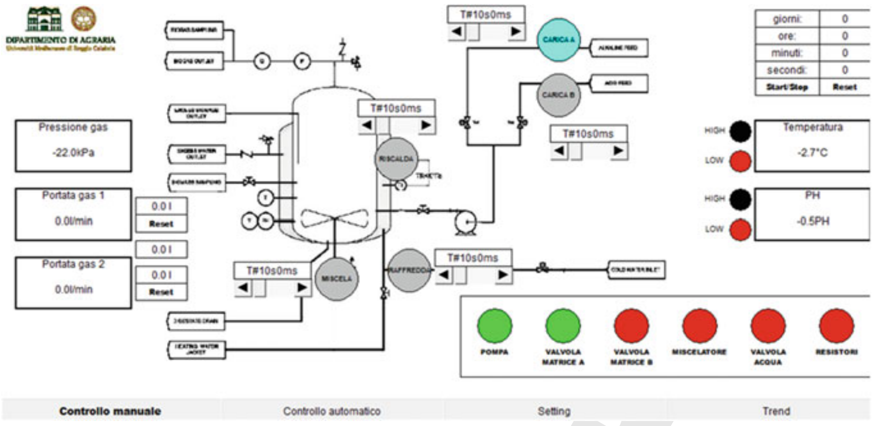

Fig. 3 Manual control window and loading activation of matrix A

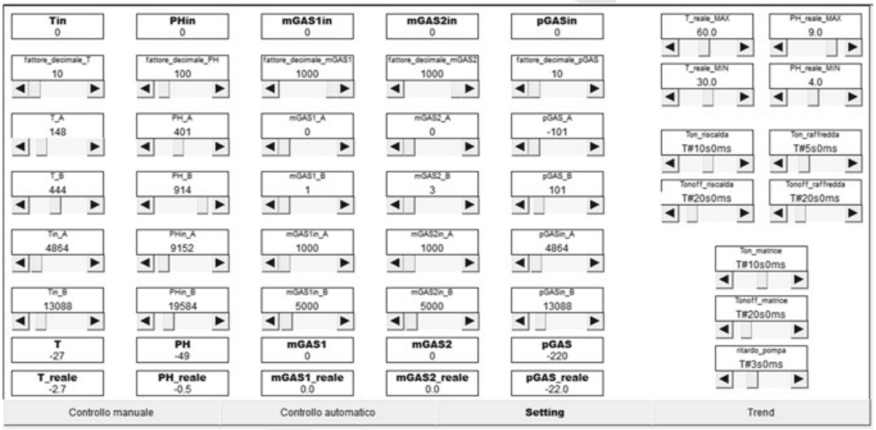

Fig. 4 Setting window

Automatic Control Mode

In this configuration, the control of the individual actuators is not allowed but it is only possible to start or stop (by clicking on the START button) the operation of the digester. In this mode, the PLC will automatically intervene on resistors, electric pump and solenoid valves whenever a correction of the temperature and pH values is required.

The Graphical Interface also provides a "Setting" window, shown in Fig. 4, which supplies the tools to tune and modify the variables that affect the control logic, that is:

- T_reale_MAX = maximum temperature value;
- T_reale_MIN = minimum temperature value;

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- PH_reale_MAX = maximum PH value;
- PH_reale_MIN = minimum PH value.

The heating and cooling of the substrate occur cyclically. That is, the resistor heats the substrate intermittently through the succession of on and off phases. This solution has been chosen because it allows the management of the thermal inertia of the system. The intermittent heating and cooling phases provide the system with the time necessary to reach the preferential temperature conditions, avoiding excessive overheating or under-cooling. From the setting window, it is possible to modify the intermittence intervals.

The loading phase of matrices A and B also occurs cyclically. That is, the pump supplies matrix A or B intermittently through the succession of on and off phases. The intermittent loading phase provides the system with the time necessary to reach the preferential pH conditions, avoiding making the global matrix too acidic or too basic (due even in this case to the inertia of the system). From the setting window, it is possible to modify the intermittence intervals. The loading phase of matrices A and B takes place in two steps: in the first step, the solenoid valve related to the matrix to be loaded (A or B) is activated; then the electric pump with the task to pump the corresponding matrix is activated. This delay is necessary to be sure that the solenoid valve has performed a complete rotation.

On the right side of the "Setting" window, the necessary variables to calibrate the measurement of the temperature, pH, flow and pressure sensors are shown. In detail, for each measurement, a proportionality coefficient was applied between the analogical signal and the measurement itself.

Finally, a "Trend" window (Fig. 5) shows the real-time trends of the measurements acquired by the sensors and supplies information on:

- substrate temperature;

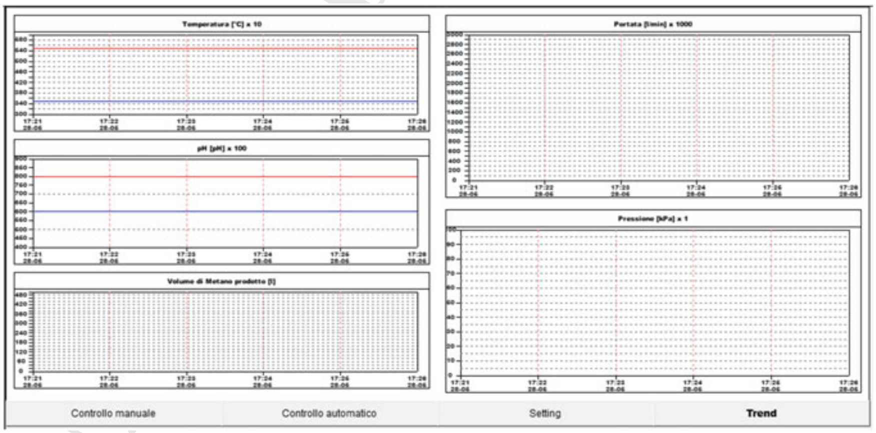

Fig. 5 Trend window

- pH of the substrate;
- flow rate, pressure, and cumulative volume of the produced biogas.

The performed measurements, in addition to being displayed in the Setting window, they are saved in text files. The data history stores not only the pH values, flow rate, pressure, and temperature but also the operating status of the actuators. A history file is automatically created and saved in the notebook.

3 Conclusions

The control logic presented in this paper, and developed for the management of a medium-scale digester plant through a smart automation system is characterized by flexibility and operating easiness. Such an equipment, represents a useful solution, particularly if used in small and medium olive oil mills, as it allows to manage sustainably olive mill by-products and recover them in renewable energy, which can be used *in situe* according to a multifunctional approach considering, both economic and environmental aspects [9, 10].

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References

1. Benalia, S., Falcone, G., Stillitano, T., De Luca, A.I., Strano, A., Gulisano, G., Zimbalatti, G., Bernardi, B.: Increasing the content of olive mill wastewater in biogas reactors for a sustainable recovery: methane productivity and life cycle analyses of the process. Foods **10**, 1029 (2021). https://doi.org/10.3390/foods10051029
2. Zema, D.A., Zappia, G., Benalia, S., Zimbalatti, G., Perri, E., Urso, E., Tamburino, V., Bernardi, B.: Limiting factors for anaerobic digestion of olive mill wastewater blends under mesophilic and thermophilic conditions. J. Agric. Eng. **49**(2), 130–137 (2018). https://doi.org/10.4081/jae.2018.792
3. Singh, A., Kumar, V.: Recent developments in monitoring technology for anaerobic digesters: a focus on bio-electrochemical systems. Bioresour. Technol. **329**, 124937 (2021). ISSN 0960-8524. https://doi.org/10.1016/j.biortech.2021.124937
4. Ward, A.J., Bruni, E., Lykkegaard, M.K., Feilberg, A., Adamsen, A.P.S., Jensen, A.P., Poulsen, A.K.: Real time monitoring of a biogas digester with gas chromatography, near-infrared spectroscopy, and membrane-inlet mass spectrometry. Bioresour. Technol. **102**(5), 4098e4103 (2011).
5. Falk, H.M., Reichling, P., Andersen, C., Benz, R.: Online monitoring of concentration and dynamics of volatile fatty acids in anaerobic digestion processes with mid-infrared spectroscopy. Bioprocess Biosyst. Eng. **38**(2), 237e249 (2015)
6. Jin, X., Li, X., Zhao, N., Angelidaki, I., Zhang, Y.: Bio-electrolytic sensor for rapid monitoring of volatile fatty acids in anaerobic digestion process. Water Res. **111**, 74e80 (2017)
7. Cruz, I.A., de Melo, L., Leite, A.N., Melquiades Sátiro, J.V., Santos Andrade, L.R.,Torres, N.H., Cabrera Padilla, R.Y., Bharagava, R. N., Tavares, R. F., Romanholo Ferreira, L. F.: A

new approach using an open-source low cost system for monitoring and controlling biogas production from dairy wastewater. J. Clean. Prod. **241**, 118284 (2019). ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2019.118284

8. Bernardi, B., Benalia, S., Zema, D.A., Tamburino, V., Zimbalatti, G.: An automated medium scale prototype for anaerobic co-digestion of olive mill wastewater. Inf. Process. Agric. **4**(4), 316–320 (2017). https://doi.org/10.1016/j.inpa.2017.06.004
9. Stillitano, T., De Luca, A.I., Falcone, G., Spada, E., Gulisano, G., Strano, A.: Economic profitability assessment of Mediterranean olive growing systems. Bulgarian J. Agr. Sci. **22**(4), 517–526 (2016)
10. Bernardi, B., Falcone, G., Stillitano, T., Benalia, S., Bacenetti, J., De Luca, A.I.: Harvesting system sustainability in Mediterranean olive cultivation: other principal cultivar. Sci. Total Environ. **766**, 142508 (2021). https://doi.org/10.1016/j.scitotenv.2020.142508

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