

DEVELOPMENT OF AN INTEGRATED SYSTEM FOR THE OPTIMISATION OF SBR'S

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Abstract: This paper presents i) a synthesis of the EOLI supervision system for optimizing both the biological reaction phases and the settling phase of Sequencing Batch Reactors (SBR) performing carbon and nitrogen removal from urban or industrial wastewaters; ii) a summary of the integration capabilities of the integrated system developed by an industrial partner of the project to propose both the hardware and the software of the EOLI solution under a unified framework.

Keywords: Sequencing Batch Reactors (SBR), hardware and software integrated solutions, supervision, telemonitoring and control

INTRODUCTION

The EOLI project aimed at developing an integrated system for the on-line optimization of biological SBR processes treating urban and industrial (including toxic) wastewaters. As a demonstration example, in a first part, this paper presents the advanced framework of the supervision system which has been developed to manage the reaction phase of an aerobic SBR treating dairy wastewaters. In a second part, both hardware and software capabilities of the EOLI integrated systems are presented.

1. SUPERVISING AN AEROBIC SBR WITH ADVANCED INSTRUMENTATION

The EOLI Decision Support System (DSS) is completely modular. A number of different modules have been developed with respect to the actual available instrumentation. To summarize, three supervision levels distinct modules have been proposed :

- An industrial DSS including the signal processing modules when a low instrumentation is available : this system is suitable when only DO/Redox potential and/or pH measurements are installed on the system. This module is presented elsewhere [1].
- A DSS able to deal with qualitative and quantitative information delivered by advanced instrumentation including Titrimetric sensors such as MARTINA [2][3], Biosensors such as TITAN [4][5] or UV sensors [6].
- A specific DSS devoted to the management of the sludge settling capabilities. Details about this part are given in [7].

Taking into account the information provided by the TITAN (cf. the deliverable D3.2) and/or by the UV sensor (cf. the deliverable D3.3) that have been developed within the framework of EOLI, the basic idea of the actual supervision system is to perform on-line a mass balance on the carbon and on the nitrogen. In other words, the idea is to verify if the actual oxygen consumption fits the theoretical oxygen needs with respect to the available knowledge about the yields of the different involved bioreactions. The balance which is realized is based on the following calculations.

The oxygen consumption in the reactor during the aerobic phase of a treatment cycle can be described by the following equation:

$$O2_consumption = O2_nitr + O2_ox_aer + \text{endogenous respiration} \quad (1)$$

where $O2_nitr$ is the oxygen requirement for the nitrification process, due to autotrophic biomass, $O2_ox_aer$ is the oxygen requirement for the organic matter oxidation process, performed by the heterotrophic biomass and the "endogenous respiration" is due to both autotrophic and heterotrophic biomasses ("decay" autotrophs and heterotrophs).

According to the Activated Sludge Model ASM1, nitrification process and organic matter oxidation in the aerobic phase can be related to the dissolved oxygen concentration with the following relationship, that link substrates depletion to bacterial growth :

$$\frac{S_{NH}}{Y_A} + \frac{(4.57 - Y_A)}{Y_A} O_2 \propto X_{BA} \quad (2)$$

$$\frac{S_s}{Y_H} + \frac{1 - Y_H}{Y_H} O_2 \propto X_{BH} \quad (3)$$

respectively for the autotrophs and for the heterotrophs so as the oxygen consumption in the reactor during the aerobic phase can be expressed as :

$$O_2 \text{ consumption} = (4.57 - Y_A)SNH + (1 - Y_{BH})S_s + \text{endogenous respiration} \quad (4)$$

where S_s is the amount of organic matter (expressed as grams of COD) that are oxidized.

Typically for the process at LBE-INRA, we can assume that in standard conditions of operation the influent's organic matter content is almost completely depleted, since the ratio COD_{tot}/COD_{degradable} is close to 1. Therefore we can assume that the amount of organic matter oxidized (S_s) is equal to : COD_{tot} – COD_{den}, where COD_{den} is the amount of organic matter required to achieve complete reduction of nitrogen oxidized compounds present in the reactor at the beginning of the anoxic phase. The stoichiometry of the relationship between COD and N denitrified allows us to calculate the COD requirement as follows :

$$COD_{den} = \frac{N - NO_x \cdot 2.86}{1 - Y_{HD}} \quad (5)$$

The amount of N-NO_x to be reduced by means of denitrification can be estimated both by the TITAAN and/or by the on-line UV sensor : the analysis should be performed just before the beginning of a new anoxic phase. The TITAAN can estimate the amount of N-NO_x with a recently developed titration modality (this modality is still not implemented on-line , but it has been widely tested at lab-scale with the titration unit MARTINA). For details on hardware sensors see EOLI WP3 3rd year report and related deliverables.

The TITAAN hardware sensor is also able to provide on-line estimations of the amount of the influent's TKN. On the basis of this data, and with the hypothesis that the amount of COD_{tot} of the influent is known, it is possible to predict the amount of nitrogen to be nitrified in the aerobic phase as :

$$SNH = TKN_{tot_inf} - TKN_{assimilation/synthesis} \quad (6)$$

and TKN_{assimilation/synthesis} can be calculated on the basis of the ratios : BOD : N : P = 100 : 5 and 1 respectively, that corresponds to the typical nutrient ratio for bacterial growth in activated sludge systems.

We can assume that the amount of inert nitrogen content of the influent for the LBE-INRA process is negligible. A software tool was developed to measure the effective oxygen consumption during the aerobic phase of the SBR cycle. For this evaluation, a reliable

measure of KLA is necessary, since we use the equation that describe the oxygen consumption :

$$O_{2\text{consumption}} = K_L a \cdot \int (S - O_2) dt \quad (7)$$

where S is the instantaneous value of oxygen concentration during aerobic phase in the absence of substrate (blue curve in Figure 1) and O_2 is the oxygen concentration profile in the presence of substrate to be removed (red curve in Figure 1).

An automatic computation routine has been implemented on the LBE-INRA reactor, in order to provide KLA measures from two different DO probes located at different positions in the tank : the measures are performed at the end of the first daily cycle, when theoretically all substrates should have been removed.

The curve S in figure 1 can be calculated as the solution of the differential equation :

$$X' = K_L a \cdot (O_{2sat} - S) \quad (8)$$

At the end of each aerobic cycle, the software can calculate the amount of oxygen used to oxidize substrates by means of equation 7. It is important to notice that the oxygen consumption evaluated with eq. 7 allows one to avoid the evaluation of the endogenous respiration rate, assuming that this contribution is constant both in the presence and in the absence of substrates.

SO₂mgO₂/L-time

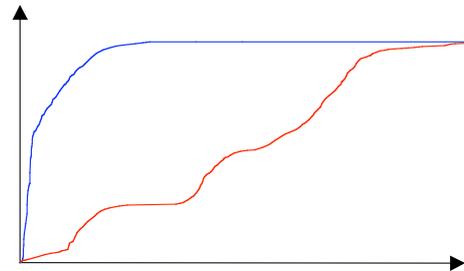


Figure 1 : Oxygen curves in absence (blue) and in presence of substrates (red)

With the oxygen consumption data and the amount of TKN in the influent that is fed to the SBR, we can use the oxygen mass balance to detect the amount of COD_{tot} that was fed to the plant in the actual cycle, and evidence situations as over/under load of organic matter rather than nitrogen. Data are automatically stored in the EOLI database in order to follow the evolution of the process. A series of tests with different influent COD/N ratios have been performed.

To validate the procedure, a series of chemical analysis were performed on the influent (to know the real amount of organic matter and TKN in the feeding) and the oxygen consumed was evaluated by

the oxygen mass balance described above. We used the typical ASM1 values for the parameters YA and YBH in the equation 4 while for YHD in equation 5 the value 0.52 gCOD/gCOD, reported for milk serum treatment (Ohron, 96), was used. The value obtained by calculation were compared to the oxygen consumption estimated by the supervision software, and the first results obtained are plotted in Figure 2.

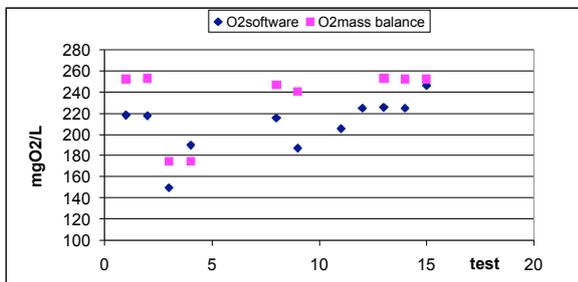


Figure 2 : Comparison between oxygen consumption estimated by mass balance and by the supervision software

The interface of the system is represented in the following figure :

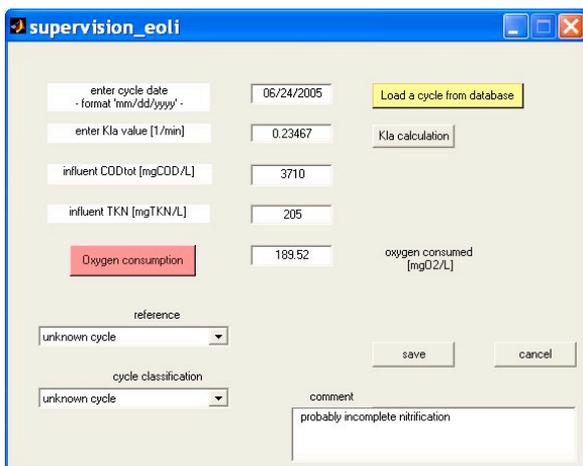


Figure 3 : User interface of the supervision system in the case 2

2. THE INTEGRATION OF THE EOLI SYSTEM

It should be noticed here that only the most important functionalities from users point of view are described hereafter. For further details, please refer to the deliverables D8.3 and D8.4.

Within the project, there are several wastewater treatment plants that are being fitted with the EOLI system, adapted to their individual needs. These are the project's integrated systems. Integration means the setting up and basic testing of the EOLI modules on a SBR plant site, within the framework - the middleware - that allows them to communicate with each other and with the SBR process itself. The integration activity involves two real physical plants with the aim at validating the reliability and customisability of the system: the pilot scale plant at ENEA (Italy), and the pilot- scale plant at INRA

(France). These plants have very different characteristics, and thus it is an effective test for the EOLI approach to be able to integrate them all within the same framework.

The whole integrated system produced at the end of the project is characterised by the high level of modularity pursued for the integration that makes it possible to configure, to enroll, to enable or to disable all the possibly numerous components. Therefore the system can be applied at plant of different size, under different sensors network configurations. The experience from the installation, running and maintenance at two different pilot plants, the ENEA and the INRA ones, confirm this result. The full customisability, that was a key requirement for the development of the system, is a consequence of this high and reliable modularity.

In order to test and to demonstrate the potentialities and capability of the EOLI system as far as the data management and integration, other three plants located out of Europe, the IbTech full scale plant in Mexico and the two lab plants at UU have been logged to the EOLI remote server.

These plants have to be considered as examples of architectures compliant with the EOLI software supervision system, equipped with monitoring and control systems built up with off the shelf solution. This enforces the policy for exploitation and dissemination of the results of the EOLI project: the software main frame and the whole monitoring and control systems developed provide general features and capabilities that are customisable to many other types of EOLI compliant installations.

In this paper the two software packages, the local software and the remote software, developed for the local and remote management of the whole integrated system will be described. The basic features of these two packages have been the object of the integration and validation activity at the two pilot plants: they will be presented by way of the description of the graphical user interfaces and of the tools, based on panels, menu and controls, they provide to the operator, both the local and the remote one.

Most of these features and the functionalities reported and described below can be considered basic for the modularity of the two software packages, in the sense that through them the operator, both at local and remote level, is provided with a real capability to configure and to customise the whole integrated system with no constraints concerning the characteristics and size of the plant.

The EOLI project is based on the idea that each remote WWTP is connected to a Remote Server Machine – located at a remote control centre - in order to upload measured data and alarms and

download control actions. This Remote Server is essentially a supervisor system which implements a distributed control architecture. It has been chosen to use Internet as the main connection infrastructure between the Remote Server and each plant; this is because of the flexible, inexpensive and widespread nature of this medium.

The core, both at the remote control centre and at the local plant, is a relational database and it is used to store all the data gathered (measurements), generated (commands), transferred and managed by the EOLI system.

At the local plant level, the main frame software is organized in modules. Software modules can be enrolled into the system to implement features and functionalities.

The EOLI software architecture is based on the client/server technology in which different modules implemented for different purposes, can share the same resources using a relational database management system (DBMS) that is introduced to replace the limitations of the file sharing architecture: the client/server technology is a versatile, message-based and modular infrastructure that is intended to improve usability, flexibility, interoperability and scalability.

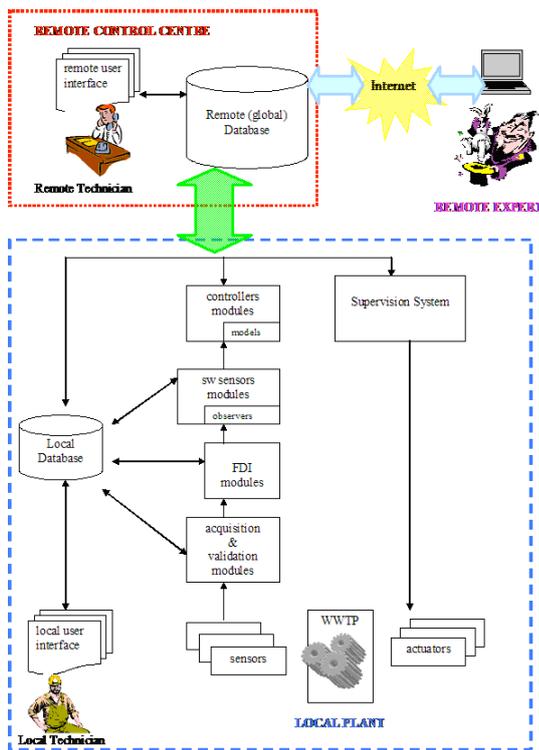


Figure 4 : The main window of the software

As far as the hardware architecture, in the EOLI project the approach addressed is the development of a WWTP digital platform designing an embedded electronic main board based on ARM technology and equipping each sensor and actuator with an embedded electronic slave board submitted to the main one. In the Figure 4 a schema of the overall architecture of the EOLI system is represented.

3. THE LOCAL SOFTWARE

SPES Gateway is the name chosen for the local software and it is very useful to understand the role that it has inside the EOLI system: it is the gateway between the hardware components of the system (the embedded electronic boards) and the high level software components running on the local PC. All the actions (acquisitions and actuations) scheduled by an operator or by a running software module, pass through it because of it constitutes the lowest level of communication with the plant, and also for this reason it is considered the zero-layer for the software architecture.

The interaction with the process is implemented using a serial link: from the PC through the RS232 port, serial tokens are sent to ask for data or to impose commands. These tokens are received and parsed – according to a protocol - by an embedded system (ARM technology based) and immediately applied to the plant.

The communication with the remote database is realized using XML text files sent to the remote server using Internet as media: a PHP parser, that runs in the web server, extracts the data from the XML files and stores them in the tables of the remote database.

As far as this zero-layer, it has the main role as the Master in the connection and communication flow with the process: actually the SPES Gateway requests the data to the plant filling the local database, according to a sample time chosen by the operator, and it applies the actions when they are scheduled into the same database.

The main tasks of the local software, the main window of which is represented in the Figure 5, are:

1. Setting the acquisition sampling time of the system.
2. Requesting the data according with the sampling time chosen.
3. Giving a complete access to the hardware configuration.
4. Applying all the actions that are scheduled by software modules or human operators.
5. Sending the data to a remote database server in order to store them in the server machine.
6. Enrolling any executable modules in the system giving a full control on it.
7. Manage the local database maintenance automatically: the software erases the acquisitions older than a certain amount of days chosen by the local operator (default value is 3 months).

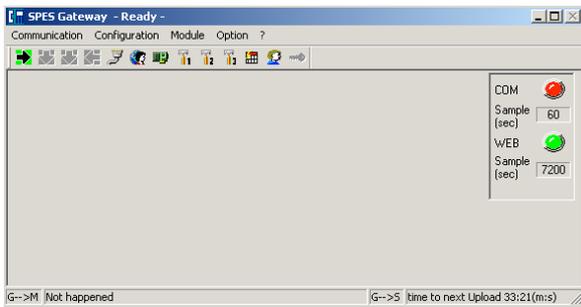


Figure 5 : The main window of the software

4. THE REMOTE SOFTWARE

The EOLI remote interface is available only if the user is provided with an Internet Browser such as Microsoft Internet Explorer , Mozilla, Netscape, Firefox , all at least in the last releases of the software and obviously with an internet connection. These actually are the only necessary tools for the connection to the remote interface system.

First of all, after we have opened our favorite browser, we fill the address bar with the URL of the EOLI server then we push the go button. The first page of the EOLI server is the login page in the Figure 6 :

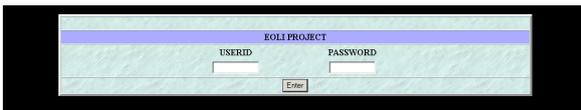


Figure 6 : Admittance control panel

We have to fill the user id and password fields with a valid account in order to enter in the site, and only the EOLI administrator is able to give these grants for the access. Anyhow a special account for a demo visit with a userid and a password both equal to "demo" is active. If we use wrong login parameters, the system warns us with a different panel for an unauthorized attempt, and we can try the access again.

After we succeeded the login procedure, we can choose which plant we want to check: the available plants depend on the grants of access the EOLI Administrator assigned for our login account. In Figures 7 and 8 we have examples of the main panel look for two users with different access grants.

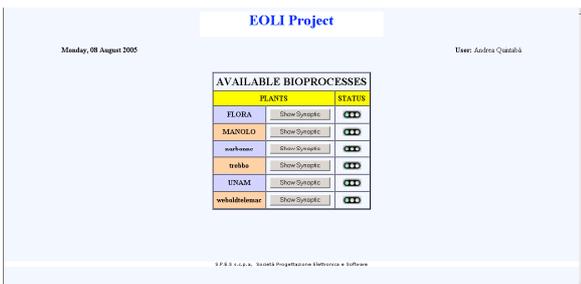


Figure 7 : Admittance control panel

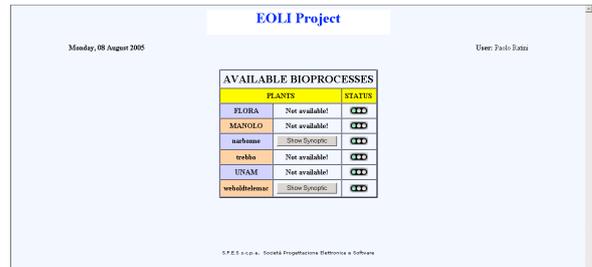


Figure 8 : Admittance control panel

We can enter the synoptic of one of the available plants with a click on the corresponding button. The synoptic represents a schema of the devices and probes really in use at the selected plant with the values of the last available data acquired displayed. In the Figures 9, examples of the structure of a synoptic are presented:

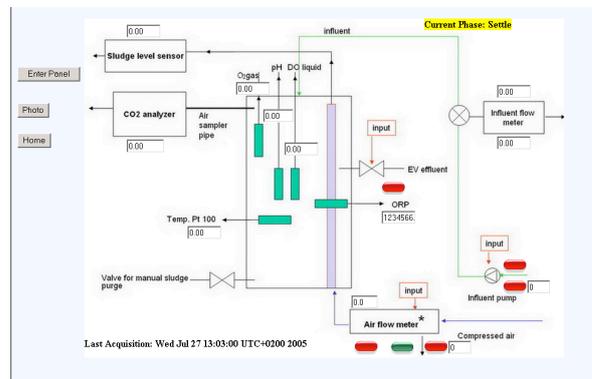


Figure 9.1 : Narbonne pilot plant synoptic with the location of probes and device

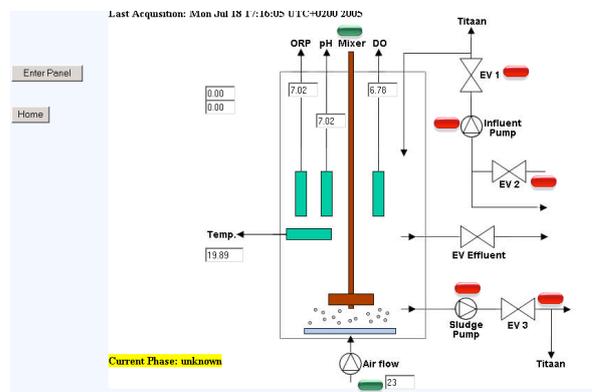


Figure 9.2 : Trebbo pilot plant synoptic

The synoptic provides several control objects (text fields and leds) that display the last available value of the variables and the actual state of the actuators (GREEN:opened/activated;RED:closed/deactivated): if we click on one of the controls, the graph of the variable during the last 8 days is shown as presented in the figures 10 :

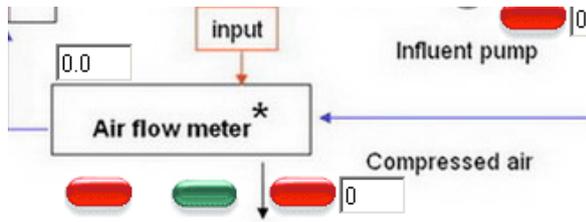


Figure 10.1 : a particular of the Narbonne synoptic

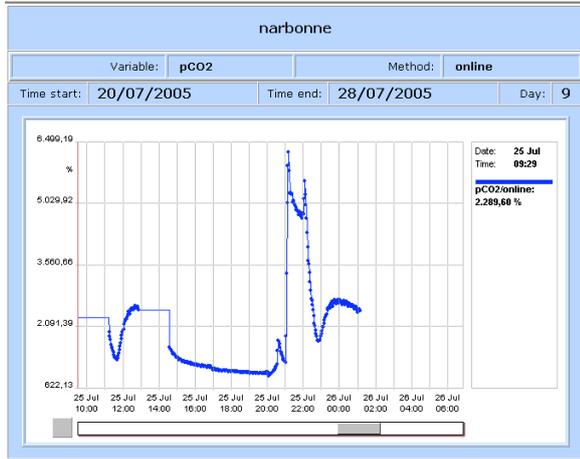


Figure 10.2 : the graph that appears when we click the input text in figure 9.1

This option is not always active: in fact if the text field bgcolor is red, this means that the probe/device linked to the variable isn't active. Clicking the Enter Panel button at the synoptic, we enter the main control panel of the plant that contains the TCC, the COMMAND, the DRAWING and the TABLE functionalities: according with the grants of our own access account we are qualified or not for the opening of each single functionality mentioned above.

5. MAIN INTERFACE

The main interface of the remote software is based on several frames and panels. Among them the basic ones are the Variable/Method Panel and the Command Panel.

The Variable/Method Panel

This form lets us to browse the variables available in the current plant, in order to draw online or download to our PC their values. Of course we have first to choose the time range in the calendar control.

We have to select the variable from the variable's list and after push the Insert button to put it in the input field as it's shown in figure 11. The same operation must be done for the method's list in which appears only the available methods for the selected variable. The Delete and Delete All buttons are useful to erase from the panel the results of our choices.



Figure 11 : The selection of a variable and his method

We can select up to 4 variables to obtain, pushing the Draw button, the graph referred to the time period selected (Figure 12) or view the data as a table pushing the Table button (Figure 13) with the option of downloading them in a txt or csv format.

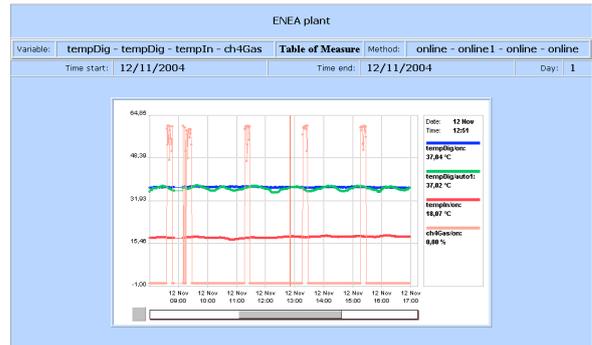


Figure 12: the graph of 4 variables in a single day

| Date | DO | REBOX |
|---------------------|-------|--------|
| 2005-09-22 00:00:00 | 4.458 | 50.947 |
| 2005-09-22 00:03:00 | 3.971 | 54.192 |
| 2005-09-22 00:06:00 | 3.406 | 56.891 |
| 2005-09-22 00:09:00 | 4.041 | 59.622 |
| 2005-09-22 00:12:00 | 3.872 | 61.390 |
| 2005-09-22 00:15:00 | 3.837 | 64.293 |
| 2005-09-22 00:18:00 | 3.977 | 64.598 |
| 2005-09-22 00:21:00 | 4.150 | 69.186 |
| 2005-09-22 00:24:00 | 4.927 | 72.182 |
| 2005-09-22 00:27:00 | 4.688 | 74.424 |
| 2005-09-22 00:30:00 | 5.019 | 78.123 |
| 2005-09-22 00:33:00 | 5.334 | 80.887 |
| 2005-09-22 00:36:00 | 5.767 | 84.004 |

Figure 13 : the data of 4 variables in a single day

The Command Panel.

When we push the CMD button, the Manual Command panel is opened (Figure 14). In the command panel are reported all the actuators enrolled for the plant with their main features:

- ACTUATOR short name of the actuator.
- ADDRESS hexadecimal address: this information is useful for a quick check of the hardware configuration .
- STATUS the last state of the actuator, RED – turned off; GREEN turned on. For the inverter type equipments it is also reported the last value of the control in terms of percentage vs the upper range limit.
- OP the possible commands that we can send to the actuators at the plant. Also in this case for the inverter type actuators it is possible to choose the percentage of the control value imposed.

6. CONCLUSIONS

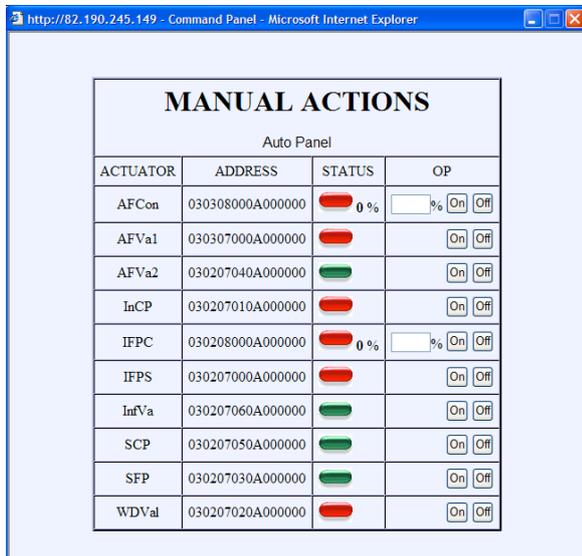
In this paper we presented the EOLI integrated supervision system. A very wide range of functions is available to local users and remote users connecting by internet.

The EOLI local software allows a full range of actions to be performed by the user, including:

- establishing communication with the plant;
- handling measurements;
- handling other tasks on plant such as maintenance;
- managing controllers;
- plotting data.

The remote interface also allows a range of operations on a plant, appropriate to the telecontrollers who will probably be situated at a different location. Depending on the privileges they may access the database and take some actions. There is also an EOLI administrator interface for setting up users and privileges.

The remote interface, accessible from anywhere in the world over the internet, allows plotting or download of data.



The screenshot shows a web browser window titled "http://82.190.245.149 - Command Panel - Microsoft Internet Explorer". The main content is a table titled "MANUAL ACTIONS" with a sub-header "Auto Panel". The table has four columns: ACTUATOR, ADDRESS, STATUS, and OP. Each row represents an actuator with its current status (indicated by a colored bar and percentage) and control options (On/Off buttons).

| ACTUATOR | ADDRESS | STATUS | OP |
|----------|------------------|--------|--|
| AFCOn | 030308000A000000 | 0% | <input type="button" value="On"/> <input type="button" value="Off"/> |
| AFVa1 | 030307000A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |
| AFVa2 | 030207040A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |
| InCP | 030207010A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |
| IFPC | 030208000A000000 | 0% | <input type="button" value="On"/> <input type="button" value="Off"/> |
| IFPS | 030207000A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |
| InfVa | 030207060A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |
| SCP | 030207050A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |
| SFP | 030207030A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |
| WDVal | 030207020A000000 | | <input type="button" value="On"/> <input type="button" value="Off"/> |

Figure 14: the Command Panel

7. ACKNOWLEDGEMENTS

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