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INNOVATIVE SCADA TEST BED INFRASTRUCTURE FOR ENGINEERING EDUCATION AND RESEARCH

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***Abstract**: In the context of growing interest from students but also from industrial companies for a solid preparation in the field of industrial information systems with applications in the energy field, extractive industry, chemical plants and automotive systems, universities have to keep up with this demand and, appropriate resources at hand, should stay ahead of the curve in offering facilities that enable competitive education. The paper introduces the development and implementation of a modern medium-scale laboratory concept in support of engineering education and research in the field of SCADA systems. The main distance process monitoring and control concepts are discussed, along with practical skills for developing applications for solving real-world projects as elements of efficient knowledge transfer. The key infrastructure levels are described: field equipment level, remote monitoring and human machine interface level, engineering/development level, communication and network level and IT backbone. We emphasize the integration of the common platform, achieved by leveraging standard based approaches, which allow interconnection of hardware and software from different manufacturers. Modern intelligent and software-intensive industrial solutions require a systems perspective with can only be grasped with applied learning and up-to-date teaching methods. By developing a robust IT infrastructure architecture, on-line learning as well as a remote laboratory approach are also enabled. The laboratory was developed within the Industrial Information Systems group at the Department of Automatic Control and Industrial Informatics, UPB, and it is envisioned that, by means of standardized interfaces, the federation of such test bed with similar developments from academia and industry will be opened up.*

***Keywords:** engineering education; scads infrastructure; industrial automation; computer networks.*

I. INTRODUCTION

Supervisory Control And Data Acquisition (SCADA) stands at the crossroad of measurement and automatic control systems with industrial information towards integration with enterprise wide IT infrastructures. The technology has evolved over the past 30 years as a broad method of monitoring and controlling large processes which encompass a vast array of application categories. SCADA technologies matured slowly during late 1970s [1]. Today, in the context of growing interest from students but also from industrial companies for a solid preparation in the field of industrial information systems with applications in the energy field, extractive industry, chemical plants and automotive systems, universities have to keep up with this demand and, appropriate resources at hand, should stay ahead of the curve in offering facilities that enable competitive education.

The implementation of a SCADA system [2], at different scales, represents a complex task which requires the preliminary acquisition of many important concepts as:

- computer architecture and operating systems;

- data acquisition technologies and sensor signal conditioning and processing;
- actuator classification, characterization and deployment;
- architecture and of programmable logic controllers (PLC), remote terminal units (RTU) and distributed control systems (DCS);
- programming languages and development environment for implementation of industrial applications e.g. the IEC 61131-3 standard defining programming languages for PLCs, such as: ladder diagram (LD), function block diagram (FBD), structured text (ST), instruction list (IL) and sequential function chart (SFC);
- High-level technical computing languages and interactive environments for identification like Matlab/Simulink and NI LabVIEW;
- Hierarchical industrial communication buses and associated networked protocols including high-speed real-time systems: Profinet, EtherCAT, DeviceNET, Profibus, ControlNet.
- Main inter-process data sharing techniques available on PCs: OPC, OLE etc.

All these elements have to be covered in order to convey a unitary background to future specialists in the field over several academic courses. In this context, we have proposed a laboratory SCADA infrastructure to serve as a reference point for developments in both modern eLearning engineering study and as a test bed for research. It allows students to enhance the above mentioned knowledge, to reach a high degree of comprehension of the induced activities during theoretical courses and to develop, with the help of exercises, industrial information systems expertise. The infrastructure is also providing research facilities in the form of hardware and software acting as test bed for adaptive and intelligent control of the integrated systems.

The rest of the paper is structured as follows. Section 2 discusses related work in the area of laboratory implementations for industrial information systems, with the aim of highlighting the particularities of our contribution. A comprehensive presentation of the underlying laboratory concept is carried out in Section 3. In order to better reflect the possibilities offered by this architecture, Section 4 includes a case study with implementation details for control applications in SCADA environments. Section 5 concludes the paper and presents opportunities for new developments.

II. RELATED WORK

Several relevant contributions are discussed in order to establish first the validity of the concept for laboratory teaching of SCADA systems as well as introduce the new contribution of the work. Authors of [2] consider the use of National Instruments LabVIEW graphical development environment for virtual instrumentation, with the associated Data logging and Supervisory Control (DSC) module to develop laboratory practices about a SCADA/HMI systems used for didactic purposes for various undergraduate courses at 1st Engineering Faculty of Polytechnic of Bari, Department of Electrics and Electronics, Italy. Paper [3] covers the design, commissioning, and functioning of a SCADA Laboratory facility for power systems at Jamia Millia Islamia, New Delhi, India. Theoretical and practical concepts for student education purpose in SCADA systems are introduced in [4]. Students are gradually developing a control application of an induction motor using an integrated automation system from Siemens – Totally Integrated Automation demo case with a distributed periphery employing Profibus and Ethernet communications. Because in engineering laboratories, an important concern is to perform experiments with a variety of equipment, apparatus, and measuring instruments, authors describe in [5] a Web-based application developed in order that teachers and students with similar objectives, irrespective of their geographical location can work together.

This paper present a new totally integrated and interconnected, logically and physically, SCADA Laboratory concept using a great variety of industrial application software: Matlab/Simulink, National Instruments LabVIEW; Siemens – Step 7 Pro, WinCC Pro; Phoenix Contact – PC WORX and Visu+, with various application in the field of energy systems, extractive industry, chemical plants, automotive systems and electric/electro-pneumatic drive systems applications. The open, flexible and scalable infrastructure leverages and integrates equipment through standards-based approaches. Dynamic role assignment of hardware and software components enables the simulation of a wide range of applications. The concept of training and research laboratory has been a constant concern in order to offer a better understanding of the theoretical concept and to benefit from the latest practical concepts of industrial information systems.

III. LABORATORY CONCEPT

A SCADA system usually is formed of a master control system known as central supervisory control and monitoring station or engineering station as well, one or more Human Machine Interface (HMI) with the help of which the operator may display information about the monitored and controlled processes. The central supervisory control and monitoring station is connected through a hardwired network to a local controller station or through a network communication (Internet, Wireless network or Global Service for Mobile Communication) to a remote controller station [6, 7].

Each controller station is connected to filed devices such as a remote terminal unit (RTU), a programmable logic controller (PLC) or to another controller that can communicate with the supervisory control and monitoring station. The controller may be programmed to determine a course of action and/or to issue alarms back to the control operator when certain conditions are detected [6, 7].

First step in designing such a laboratory infrastructure is the classification of all available resources into well-defined classes and specify the connections between them. This leads to building a formal model which does not depend on the specifics of equipment in use and allows scaling of the test-bed according to end-user requirements. Following this goal, five categories of components, which define a SCADA system have been identified:

1. Processes – represent the subject of monitoring and control through the SCADA infrastructure. They are obtained through mathematical modeling and identification and. The processes cover various categories of industrial applications, continuous and discrete such as: energy field [8], extractive industry, chemical plants, automotive systems and electric/electro-pneumatic drive systems applications. In practice, they are modeled through smaller scale laboratory platforms which incorporate the above-mentioned models.
2. Field devices – includes industrial transducers, actuators, drives and field level control and communication devices: PLC, RTU, all from different manufacturers.
3. Human Machine Interface (HMI) and Operations Stations – provide local data acquisition, monitoring and control visualization of processes and sub-processes and manual operating mode for the the human operator. These are implemented on two levels: at the local level by the operator panels with different application software according to the manufacturers and at central level by the operation stations provided with a PC client for viewing and monitoring.
4. Engineering Stations (Control system/ Supervisory control and monitoring stations) – is a collection of computers and appropriate systems input/output (I/O) that enables the operator to setup initial SCADA projects, to development the software application for PLCs and HMIs in order to monitor the state of a process and control it. These are the essential tools in commissioning interconnected parts of complex automation projects.
5. Server – represents a very powerful computer with the role of system/infrastructure coordinator and gateway to the outside through the Internet. Includes alarm function, log/database and backup functions. It assures a secondary functionality as local network server or license server for the software package. The communication and networking backbone.

The concept of the implemented SCADA infrastructure with all the above components is shown in Figure 1. We try to underline the fact that we consider flexibility as essential for a solid implementation. An example of this would be that a PC system can belong to either the engineering station class or to the operation station class, depending on requirements specifications, and moreover its role can be dynamically reassigned during the course of a project in order to reallocate resources to certain areas. In order to better grasp the concept, the classes are illustrated through real laboratory systems which belong to one, or more categories. The server and related networking components coordinate access to/from the Internet to authorized parties in order to provide realistic levels of security for such systems. In order to fully benefit from such infrastructure, each project starts with a list of desired equipment and processes and the initial role played by each one in the overall SCADA system is specified.

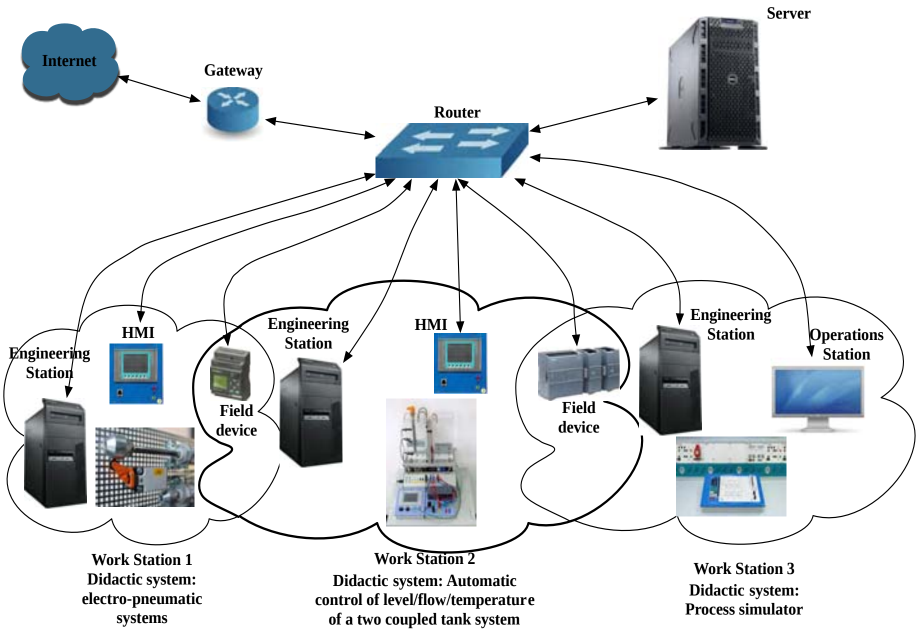

Figure 1. Laboratory concept

IV. CASE STUDY: LABORATORY IMPLEMENTATION

In order to provide a better picture of the conceptual approach, practical implementation details are discussed. This reflects the actual available equipment, both hardware and software, and its integration for some sample applications in the field of SCADA systems.

Processes cover a large area of applications as: the automatic control of level/flow/temperature of a two coupled tank system, process simulator, photovoltaic didactic system, vibration system analysis, electric drive systems and electro-pneumatic systems.

Field devices consist of PLC Siemens series such as: LOGO! S7-200, S7-1200, S7-300 and Phoenix Contact – InLine Controller 130 with digital-analog input/output modules and communications processors. Application development is done by specific programming environments for each PLC series: LOGO! Soft Comfort, MicroWin, Step7 Basic, Step7 Pro, including new versions under the TIA Portal V11 and V12 engineering frameworks and PC WORX.

The HMI devices, which provides local monitoring and control of processes and sub-processes and the human operator manual intervention are implemented as:

- local level in particular by the Siemens series – KTP600 operator panels programmed with application developed in WinCC Basic/Advanced;
- central level, with the help of stations provided with a PC client for monitoring.

The workstations have a homogenous structure. Their role as engineering or operations station is assigned logically in a dynamic manner, taking into account the applications requirements, by the server. The local network server is the central entity defining the network architecture, firewall rules and communication broker.

Figure 2 and 3 depict the hardware and software overview of the SCADA laboratory. Hardware design goes in a bidirectional fashion from field level analog and digital signals to real-time industrial controllers and HMI devices implementing intuitive user interfaces, under the constraints of a preliminary system specification. In the case of the software overview, different manufacturers of automation equipment have developed their own proprietary software systems for programming and commissioning. With the help of standard-based approaches e.g. through the use of OPC technology and open communication standards, interoperability can be assured. This also critical in teaching to provide a producer-abstract view on the development workflow for SCADA systems equipping future engineers with the tools needed to approach any situation. The laboratory is designed to test and experiment various configuration of industrial information systems, but given a fixed configuration it can provided the basis for teaching of more focused courses on individual topics.

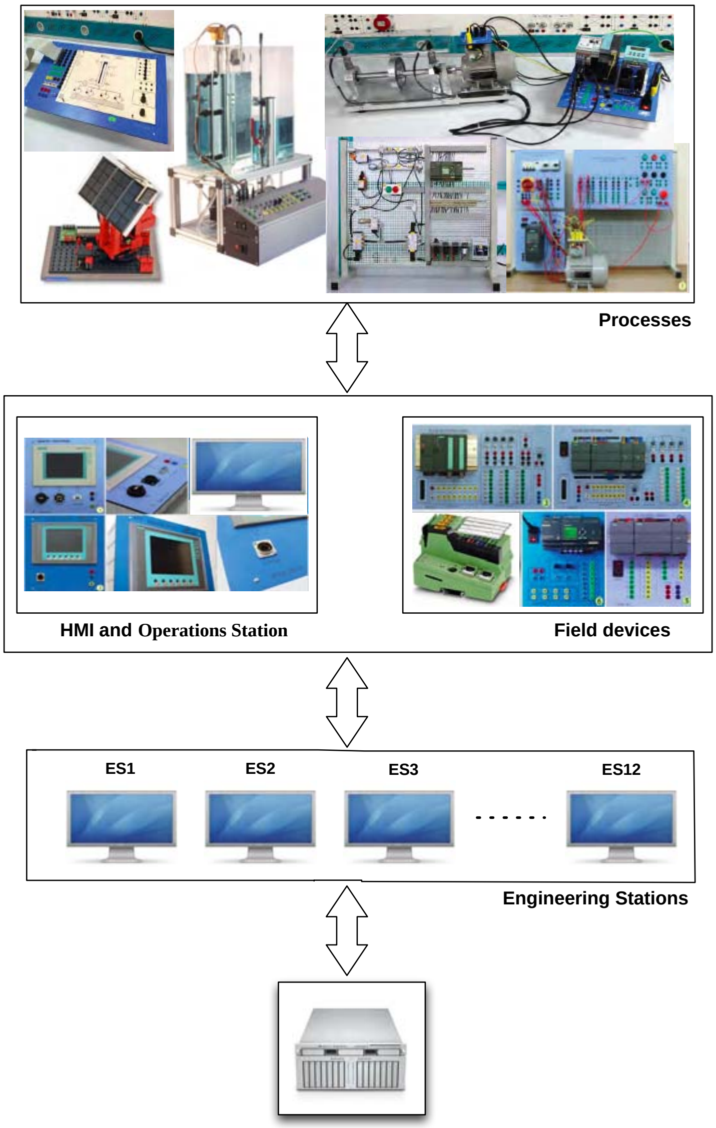

Figure 2. Hardware overview of the laboratory

A real application is discussed next to achieve a better understanding of the SCADA laboratory concept. As starting point a didactic platform for a coupled tanks systems set-up is used. The hydraulic system is based on two tank process for flow, level, pressure and temperature control as a model of a chemical plant fragment with tanks coupled through pipes and the reactant level, flow pressure and temperature to be controlled.

The system has two tanks. Water is delivered to the tank 1 from the second tank with the help of two fixed flow pumps. Drain water is provided by an adjustable flow pump through a frequency conveyor. The pressure of the main water feed line is measured with a pressure transducers, one flow transducers is used for level measurement and 3 flow sensors are used for calibration. In the system step disturbances, provided by the manual valve of the discharge pump, can be induced.

In practice, such a system, scaled to real world dimensions, is encountered as part of a series of tanks in an irrigation network, where the control and management of the water circuit is essential, or in a hydro-technic system, where keeping the level and flow parameters at present values is vital.

Using the didactical system students can various topics:

- static and dynamic characteristics of transducers and actuators;
- process measurements and data acquisition systems;
- analytic modeling and/or experimental identification of the processes;
- design of simple control structures: single controller of type P, PI or PID;

- design of multi-model control algorithm or for multi-variable processes;
- implementation of adaptive structure for time-variant processes;
- implementation of control strategies based on evolutionary techniques like fuzzy control, genetic algorithms, neural networks;
- comparative study of control and robustness performance for the implemented algorithms.

In order to enable the operation of the didactic equipment, as well as to demonstrate the integration of various software and equipment from the SCADA laboratory a level control and monitoring algorithm was developed, as shown in Figure 4. The purpose of the exercise is to adjust the level in the first tank by controlling pump "M1". The recirculation of water is provided with the help of Ma and Mb pumps. The chosen method is a control algorithm using LabVIEW. The process interface is achieved with a Modbus TCP [9] coupler meanwhile the monitoring process is implemented with WinCC 7.0 using a complex server-client architecture.

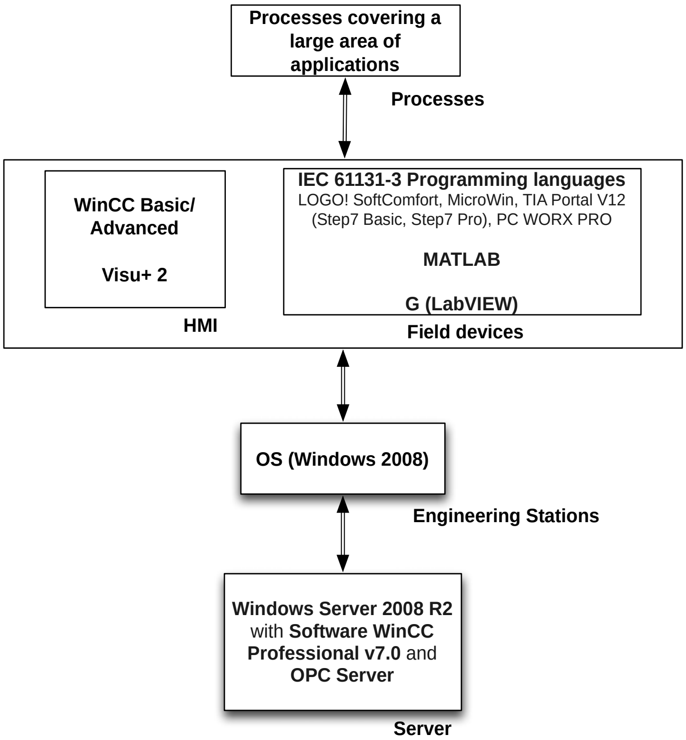

Figure 3. Software overview of the laboratory

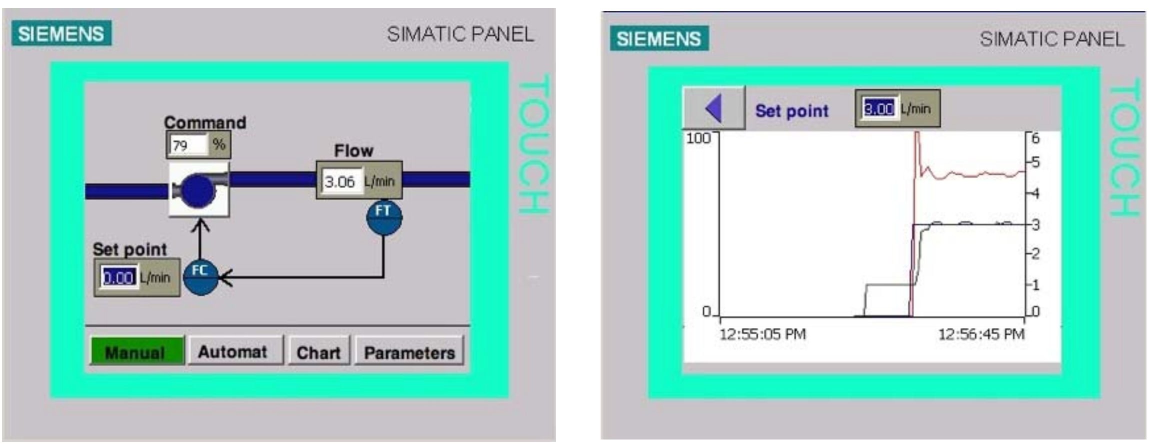

Figure 4. HMI application screens

The LabVIEW project configuration in Figure 5 includes the following tasks: LabVIEW Modbus client implementation; controller algorithm: PID, RST, etc. implementation; LabVIEW Modbus server, used for the communication with the upper level (in this case WinCE SCADA) implementation. The graphical virtual instrumentation platforms allows quick implementation through a rich set of software and component libraries, readily available for integration into individual projects [10]. The user interface is intuitive and offers access to visualization and command elements for local monitoring of the process.

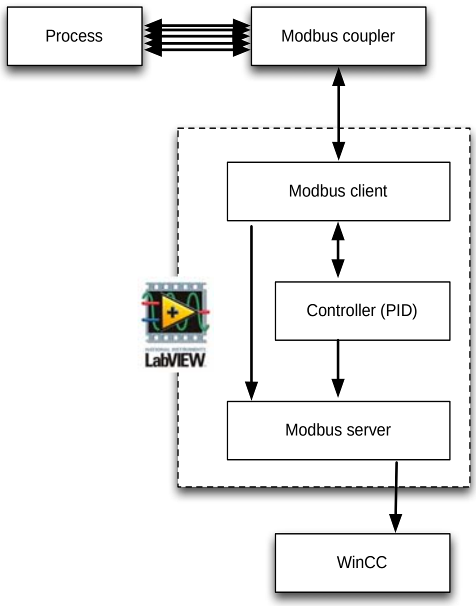

Figure 5. LabVIEW project structure

The WinCC project configuration is illustrated by Figure 6 and includes the following tasks: WinCC server configuration; operator stations attribution; process configuration; tags or process information configuration; data access configuration; operator stations configuration; HMI screens design; additional scripts design. Both configurations are deployed on the laboratory equipment in order to achieve process control through the chosen fieldbus configuration. This kind of implementation is enabled by the underlying SCADA infrastructure and represents just an example of a class of applications that can be achieved.

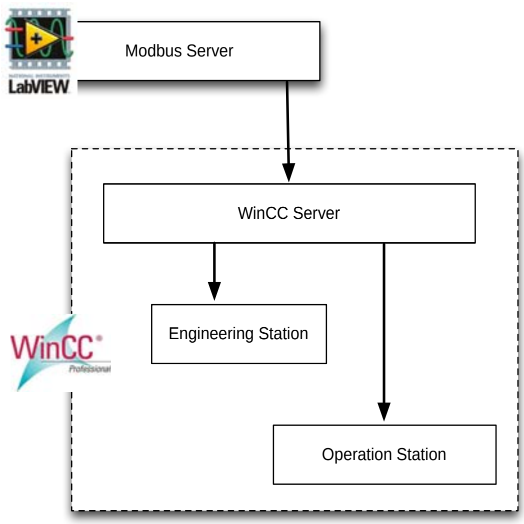

Figure 6. WinCC project structure

V. CONCLUSIONS

Modeling of a realistic development for a full supervisory control and data acquisition application using the same approach as in real case endows the student a high level of comprehension of even complex aspects of industrial information systems. This should be a common pursuit for all stakeholders involved in a sustainable higher education process: students, academic staff and external collaborators from industry and research entities.

The paper introduced the development and implementation of a modern medium-scale totally integrated and interconnected, logically and physically, laboratory concept in support of engineering education and research in the field of SCADA systems. The reference architecture provided will become a stepping-stone for education and research in this field, supporting low and high level novel developments.

Future work will cover building a library of documented projects including planning, development and application domains for various applications domains. A special consideration will be given to projects covering industrial energy management and distributed energy management systems in connexion to new paradigms in control of intelligent electric networks. These will be used both for teaching and as a basis for new research ventures taking the form of partnerships with the industrial environment.

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