Simulator for Automation and Control Systems in a Power System

Vasile Calofir, Ioana Fagarasan, Nicoleta Arghira, Mircea Stefan Simoiu,
University Politehnica of Bucharest
Faculty of Automatic Control and Computers
Bucharest, Romania
{vasile, ioana, nicoleta, mircea}@shiva.pub.ro

Grigore Stamatescu, Cristina Nichiforov, Sergiu Stelian Iliescu
University Politehnica of Bucharest
Faculty of Automatic Control and Computers
Bucharest, Romania
{grig, cristina, iliescu}@shiva.pub.ro

Abstract— **Through the future Smart Grid influenced by the challenges brought by distributed and unpredictable generation, limited energy storage infrastructure or shifting consumption patterns, the real-time large-scale system control becomes a necessity. When several energy concepts are translated into simulated processes, it is important to implement and test a large range of applications from process control, electrical grid protection systems, automatic line/reserve switching, monitoring and control of energy systems, for training reasons. Energy applications can vary from generation, transport/distribution and consumption, these covering a wide area of applications of discrete and continuous control. In this context, the paper presents the simulator system architecture, implemented applications and field necessity. As shown in the paper, the simulator applications vary from generation control to load control, including various specific automation functions and energy management in the grid.**

Keywords— control systems, power system, simulator, hardware and software open architecture, virtual laboratory

I. INTRODUCTION

Throughout the past decade, technology proved to be an important factor in many educational environments. In the context of preparing future engineers for entering the work field, an important matter resides in making study classes more practical and efficient by using technology.

In many industrial areas, working with different specialized equipment is essential. In classes, describing the working principles of such devices is, often, not enough. A practical approach is needed for the students to understand how an equipment works. This implies having several such devices at disposal, as well as organizing students in groups to work with them. Sometimes, using different equipment for class applications could be expensive due to the acquisition and maintenance cost of the industrial equipment. Especially for power system engineering classes the cost of real equipment is important and therefore simulation devices or software could be used to scale the real situations. In this context the paper proposes a simulator that could replace different power system components, theirs automation logic and devices or different operation scenarios.

Several solutions to the issues mentioned above appeared in the form of simulation platforms, like MATLAB (especially the integrated toolbox Simulink) and LabVIEW, where students can individually implement different working scenarios of a system by simulating its mathematical model [1]. Of course, it was a step forward, but further work was required in this direction. After the vast development of Internet services, several remote access experiments were implemented [2, 3], often involving both a physical equipment and a software components, [4]. For example, an equipment could be remotely controlled through a web server implemented in LabVIEW. Moreover, the control interface could be accessed on a web platform through TCP/IP. As such, students could perform scenarios on the AC motor in an efficient and organized manner [5]. However, the LabVIEW interface is limited in offering multiple functionalities in terms of organization, restricted access or support. A better solution with extended software capabilities and open hardware architecture is needed.

The paper proposes, in section II, a hardware architecture developed with suitable industrial technologies, offering certain advantages from multiple points of view. In the third session of the paper a software architecture is presented to underline the possibilities and opportunities of such a system in a technical educational environment. Furthermore, some realized applications from the power system field are presented in order to test control logic or devises implemented in real field. The final section of the paper presents a case study, from the power system automation field, an Automatic Circuit Recloser (ACR) with time delay.

II. HARDWARE ARCHITECTURE

The simulator hardware design for implementing control experiments, together with the simultaneous/remote access capabilities is presented in Figure 1.

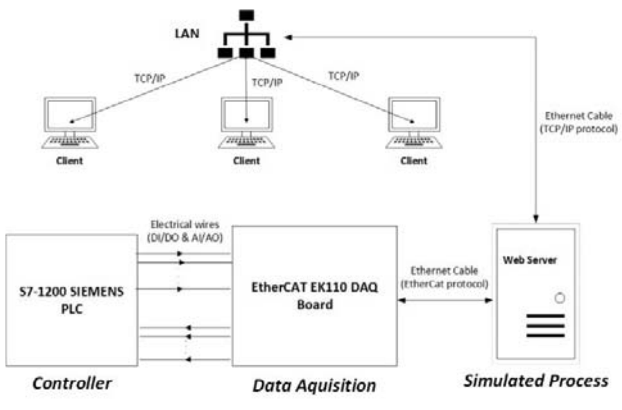

Figure 1 The proposed hardware architecture for the virtual laboratory

2379-0482/19/$31.00 ©2019 IEEE
DOI 10.1109/CSCS.2019.00066

The focal point of the architecture is the web server which runs the web interface and the process simulation simultaneously. In this architecture, the controller (programable logic controller – PLC) is responsible with the implementation of the control algorithm. This solution is suitable for multiple clients who want to visualize the process remotely, as well as for simulating multiple processes.

The proposed solution offers many advantages. The possibility to remotely view and interact with the process from different locations at the same time proves to be an important aspect from an educational point of view. Furthermore, the modular structure of the DAQ Board provides the possibility of implementing multiple control solutions simultaneously. For example, a scenario can be conducted using the first 5 DI/DO ports on the board, another scenario can be implemented simultaneously using the next 5 ports and so on.

Also, using the EtherCat protocol provides an advantage in terms of speed and flexibility, [6]. Firstly, data is transmitted at a large bandwidth, allowing very fast processes to be controlled. Secondly, it provides an open architecture since different PLCs from various producers can be used in the control structure.

Furthermore, the implementation cost for the solution is relatively small with respect to the possible scenarios that can be implemented.

A. *The simulator hardware*

A more detailed simulator architecture is proposed in Fig. 2. It includes a computer (that can be replaced by an embedded PC with touch panel for control), data acquisition boards (DAQ1, DAQ2) and PLC.

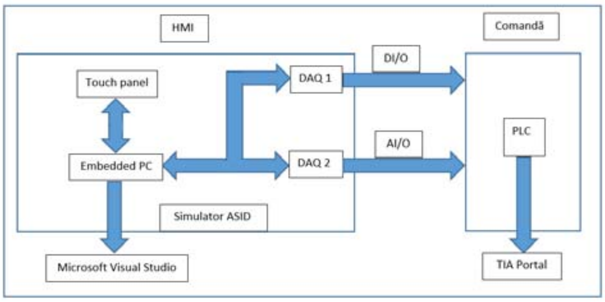

Figure 2. Simulator hardware block diagram

The EtherCatDAQ Board acts as an interface between the control component and the main web server. It is a modular device which allows multiple digital inputs/outputs (DI/DO) and analog inputs/outputs (AI/AO) modules to be attached to it. The PLC communicates with the simulated process through the DAQ boards. The controller commands are received through AI/DI ports and sensor readings are sent from AO/DO ports. The communication between the two elements is done with electrical hard wires.

The energy process is simulated on a computer which also acts as a web server. The server must be connected to the DAQ Board with an Ethernet cable. This allows data communication between the DAQ board and the web server through the EtherCat Protocol, a dedicated protocol characterized by fast and flexible data transmission.

B. *The remote acces system hardware*

The remote connection system cab part of a virtual laboratory, interconnecting several hardware devices. Several clients can access the web interface on an Internet browser and they can interact with the simulated process through a TCP/IP communication, [7]. This type of interaction means that a client can view data and can also modify certain parameters. However, only computers in the same network (LAN – local area network) with the web server can access the interface.

III. Software Architecture

A proposal for the simulator software architecture is depicted in Fig. 3 for a better understanding of how devices and technologies interact with each other at the software level. The software framework used in this solution allows the simulation of discrete mathematical models of continuous and combinational processes to be executed in real time, while sending process-related data to a web interface. In this architecture, a PLC is responsible with the implementation of the control algorithm. Depending on the simulated process, various control strategies can be used.

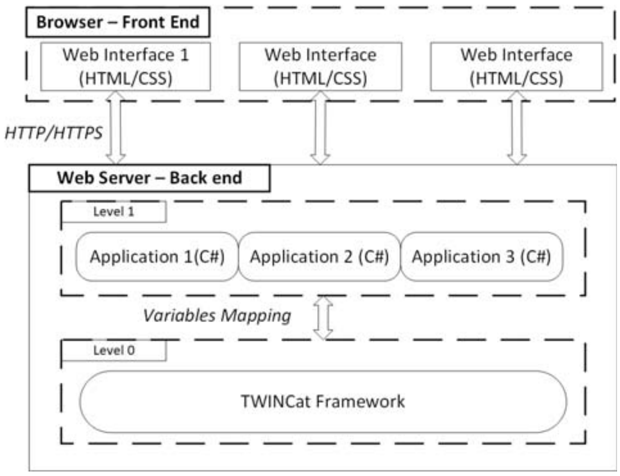

Figure 3 Simulator software framework

As it can be observed, the architecture includes only the process simulator and client software components. Since the PLC is an independent control entity, it can implement the control logic in any programming language, hence it is not included in the architecture. However, when the PLC is connected to the DAQ Board, the PLC outputs are associated with PLC variables in the Web Server's memory. This association (mapping) is implemented using the TWINCat Framework, a dedicated software provided by Beckoff. The mapping is developed in an independent software application running on the Web Server.

Regarding the process simulated on a computer, the discrete model is implemented in an application developed in C#, with elements from the ASP.NET Framework.To interact with the PLC, the application uses TWINCat functions from the respective framework. This mechanism is best described as a multilevel software structure, where the mapping application runs on the lower level and the simulation application runs on the upper level. If a control algorithm is implemented on the PLC, then the two applications must run simultaneously so that the process simulator can use the PLC variables provided by the TWINCat Framework.

These software components represent the back end of the system. The processed data is displayed on a front end in the form of a website. The interface can be accessed by clients through web browsers on computers connected to the same network to which the Web Server is connected. Also, the visual aspects of data representation are enhanced using CSS elements.

As mentioned in the previous section, the DAQ Board is a modular device and multiple DI/DO & AI/AO modules can be attached to it. This proves to be an advantage, both from a software and hardware point of view. It allows multiple simulation applications to run simultaneously, if they use independent PLC variables. Each application can have a web interface to display the process data and significant results. However, running multiples scenarios in the same time can cause delays due to the use of a lot of computational power.

Another important advantage provided by the ASP.NET Framework is that the system users can be separated in different categories, with respect to their rights. For example, each simulation application can have Administrators that can both view and interact with the model and Users who can only access the interface to view the displayed data. However, if there are multiple users who can interact with the process, a prioritization mechanism must be implemented.

IV. Applications

The simulator applications vary from generation control to load control, including various specific automation functions and energy management in the grid.

The generation control applications include the control of a three conveyors system for a thermal power plant and the control of a burner system. The latter process simulates the operation and control of a burner system with the following components: a base burner, a pilot burner, a spark transformer (TS) and two photovoltaic cells as a light/flame sensor (FVB, FVP), Fig. 4. The control and monitoring of the system is depicted on the right side of the HMI and shows the protection lamps, the activation of the control switches and the start/stop of the system (B1/B2) or the state of the 2 burners. A detailed operation and experimental testing is presented in [8].

In order to simulate the loads control in a power system, several operational situations for a three-phase motor were implemented: direct start of the motor, automatic start-delta connection start for an asynchronous motor [9], speed control of a Dahlander connection motor (Fig. 5) etc. The speed control application allows three operational speeds: low (pushbutton S1, indicator lamp H1), medium (S2, H2) and high (S3,H3). S0 button stops the system manually while S4, respectively S5 simulate an emergency stop from protection fuses (F1, respectively F2 and F3).

A complex application of the simulator simulates the supervision and control of an energy management system (EMS) in a microgrid, Fig. 6.

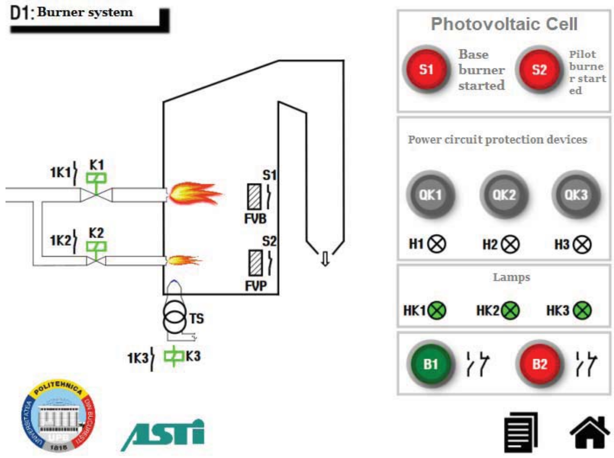

Figure 4 Burner system control simulation

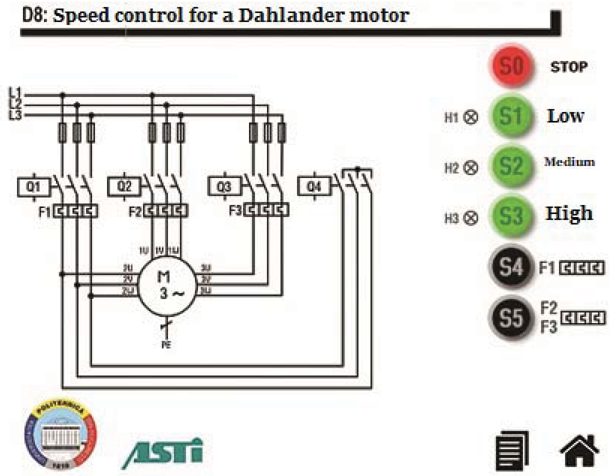

Fig. 5. Automatic speed control for a Dahlander asynchronous motor

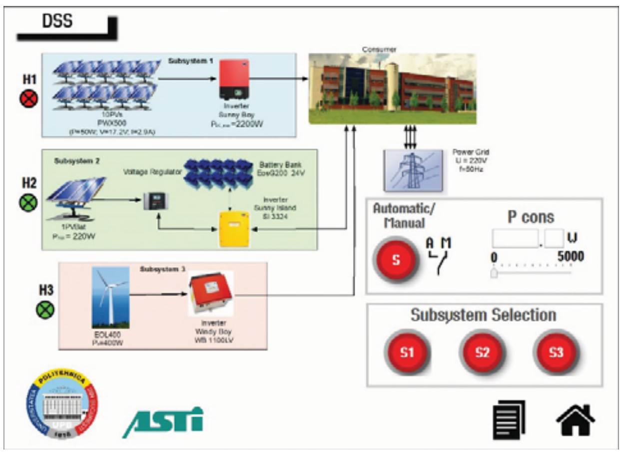

Fig. 6. Microgrid EMS application

The generation part is formed from 2 subsystems with photovoltaic panels and a wind turbine. The consumer is a residential building. Two operational states can be chosen: manual or automatic, [10]. In the manual functioning, the student will press the switch buttons for the chosen generation unit (PV1 – subsystem 1, PV2 – subsystem 2, EOL – subsystem 3 or mixed). The automatic energy management algorithm will indicate which of the subsystems will be turned on depending on the consumer load (Pcons). A decision support system (DSS) can be used for energy management system, as shown in [11, 12]. When the DSS is implemented in the PLC, the results will be indicated on the process diagram through the flagged lamps (H1, H2, H3).

V. Case Study: The Automatic Circuit Recloser (ACR-T)

To underline the utility and advantages of the power system simulator as an instrument in e-learning, focused on technical profile courses, a case study demonstrates the training possibilities of the system. The application simulates an Automatic Circuit Recloser (ACR), a system that must integrated in any electric power distribution network. The main control goal is to disconnect a faulty line in case of overcurrent and, in case of temporary fault, to reconnect the line. The process interface can be viewed in Fig. 7.

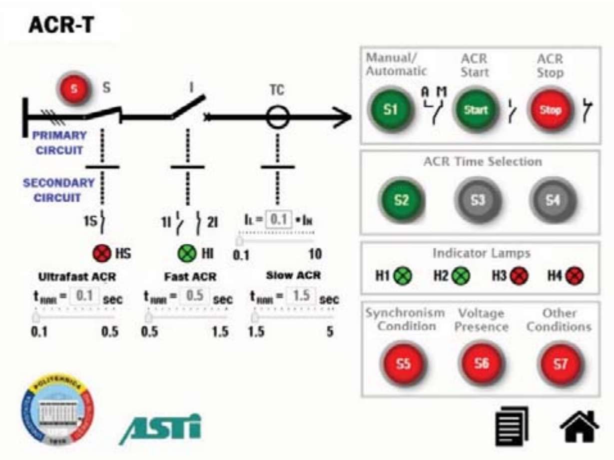

Figure 7 ACR-T application - front end interface

The main components of the ACR system are: a breaker (I), a circuit switch (S) and a current transformer (TC). Also, the system can work both automatically and manually.

A. The application technical and operational requirements

To select the operating mode, the user must press the button **S1**. The button has 2 contacts: one normally closed contact (A) for automatic mode and one normally opened contact (M) for manual mode. For a safe start to occur, the system must be activated in manual mode.

The line breaker can be manually activated by pushing the button **S**, which is connected to an auxiliary normally opened contact **1S**. This contact indicates the state of the breaker by powering up the indicator light **H2** (green stands for open breaker and red stands for a closed one).

The breaker **I** can be automatically controlled (using the PLC). The circuit switch (S) has two axillary contacts attached to it to clearly know the state of the switch (opened, closed). If the two contacts do not work, it might not be clear if the switch is opened or closed. Furthermore, the state of the switch is indicated by the lamp **HI**.

The current transformer TC permanently measures the current through the electrical line. If the current I_L is twice bigger then the line's nominal current I_N, the controller must open the breaker **I**. To conduct multiple working scenarios, the interface includes a horizontal scroll to simulate a proportional current variation through the line. The working principle of this mechanism can be explained by equation (1), where v can vary from 0.1 to 10:

$$I_L = v \cdot I_N \quad \text{(eq.1)}$$

The application is launched in manual mode (indicated by a green **H1** lamp), having the breaker and the switch in open state. The switch can be closed only if the following requirements are fulfilled:

- The breaker is closed (using the **S** button);
- The current I_L cannot be higher than twice the value of the current I_N;
- The synchronism condition (can be simulated using the button **S5**);
- There is voltage applied to the line (can be simulated using the button **S6**);
- Other conditions (simulated by the button **S7**).

For different grid operation conditions (e.g. line maintenance actions), the ACR can be deactivated using the **Stop** button.

By pushing the button **S1**, the operating mode is changed from manual to automatic (indicated by a red **H1** lamp). This operation can be executed only if the ACR has been started in manual mode and the switch state is not changed. The requirements are similar if the user wants to change from automatic to manual mode.

In automatic mode, the open breaker is indicated by a green **H4** lamp and its closed state is indicated by a red **H4**. Furthermore, if at some point the requirements are fulfilled again, the PLC controls the reconnection of the line after a specific time $\mathbf{t_{RAR}}$ has passed. Regarding this interval, the application offers 3 possibilities:

- Ultrafast opening ($\mathbf{t_{RAR}}$ = [0.1-0.5] sec);
- Fast opening ($\mathbf{t_{RAR}}$ = [0.5-1.5] sec);
- Slow opening ($\mathbf{t_{RAR}}$ = [1.5-5] sec);

Also, if I_L is higher then twice I_N, **H3** turns red, otherwise **H3** is green.

B. The ACR-T control diagram

Since the ACR represents a process based on combinational logic, the control algorithm can be implemented in two ways: with relays or on a PLC.

For the first implementation, the detailed electrical diagram for the control component of the system was designed in EPLAN Software, Fig. 7.

Based on the diagram, an input-output mapping was developed to connect the control component to the simulated process. Eventually, the DAQ Board had several digital and analog outputs configured to send state data from the process (switch and breaker state) and digital inputs to receive commands (open /close switch). The mapping was configured in the EtherCAT dedicated framework.

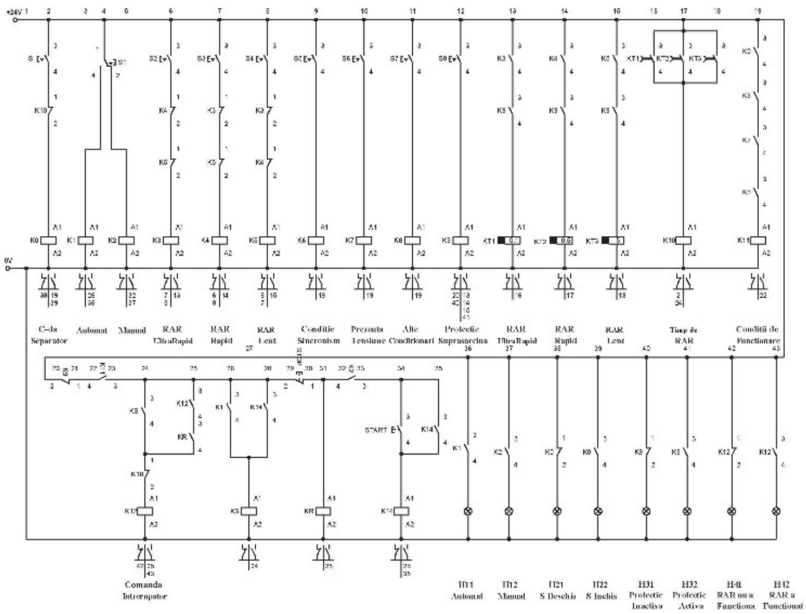

Figure 7 ACR-T Control Diagram

On the other hand, the control algorithm can be implemented on a PLC, greatly reducing the electric diagram complexity. In this context, a SIEMENS S7-1200 unit was used, including the software developing environment TIA Portal V13. A basic connection diagram between the PLC and the DAQ Board can be viewed in Figure 8.

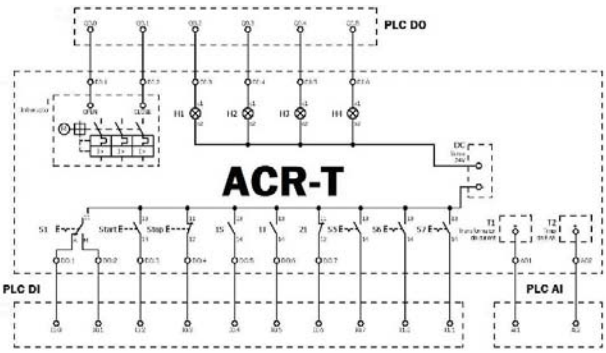

Figure 8. ACR-T PLC connection diagram

In Figure 8, the digital input and output modules of the PLC have been illustrated in the upper and lower part of the diagram, respectively. Even if the control indicators are simulated and sent from the server, the figure illustrates the pushbuttons and contacts to ease the understanding.

VI. Conclusions and Further Work

In technical profile universities, it is important to accustom the students with both theoretical and practical aspects in each field of studies. Furthermore, in experiments related to the control theory, students participate in laboratory classes and conduct various simulation scenarios on small-scale processes. As such, the institution must continuously invest towards educational equipment and provide support to make sure that each student can implement the theoretical knowledge acquired during courses. This paper presents a solution to this matter in the form of a remote access process simulator with different applications from the power engineering fields. Thus, students can simulate various processes in the power systems field, remotely, in a time and cost-efficient manner.

The proposed virtual laboratory is implemented on three devices. The process is simulated on a web server and a web interface is implemented to allow multiple clients to access the parameters of the process. The clients can interact with the process remotely, if they are connected to the network of the web server. Furthermore, a control algorithm for the process can be implemented on a PLC. A DAQ board implements a hardware interface between the PLC and the process. Also, a client can interact or view the simulated process through the web interface. The architecture presented in this paper allows multiple process to be simulated, if a discrete model of the process is implemented on the web server.

To underline the advantages and utility of the virtual laboratory, several different applications were presented and a case study was conducted. The case study is referring an Automatic Circuit Recloser with time delay (ACR-T).

The solution presented in this paper has many advantages. It is a cost-efficient open architecture, easy to maintain and flexible to further development. Furthermore, the system allows very fast processes to be simulated, since the DAQ board can work with very small sampling periods.

At this stage of implementation, only one user can interact with the process at a time and no authentication system is implemented. This suggests that there are no administrators and no simple users. In the future, it is necessary to implement a dedicated prioritization system, limiting user interaction to one at a time. Furthermore, the application should be extended to allow users to be separated into multiple categories: administrators, viewers, simple users and so on. Also, multiple processes should be simulated to benefit from the open architecture the system offers.

The need to develop such a system is underscored by the interest of the educational stakeholders: students, faculty members, high-level industry partners. It can be used in specialized training for interdisciplinary areas including edge systems in terms of modern control technologies as this open system is available to be reconfigured upon request with other technologies and critical applications for different process engineering fields. The simulator can be operated in educational environments as follows: as didactic support for learning and deepening PLCs programming languages skills; for testing various complex scenarios of some energy processes while allowing on-demand reconfiguration for some industrial systems which cannot be implemented in reality due to high costs and/or the operational safety.

REFERENCES

[1] Juan J. Fuertes, Serafin Alonso, Antonio Moran, Miguel A. Prada, Sergio Garcia, Carlos del Canto, “Virtual and Remote Laboratory of a DC Motor”, 2012

[2] Abhishek Choudhary, Shiv Aishwarya Singh, Mohd. Faizan Malik, Anil Kumar, Mukesh, Kumar Pathak and Vinod Kumar, “Virtual Lab: Remote Access and Speed Control of DC Motor using Ward-Leonard System”, 2010

[3] Aydogmus Z., Aydogmus O., “A Web-Based Remote Access Laboratory Using SCADA”, 2009

[4] N. Ignat, F. Stanculeanu, An Overview On Modeling And Simulation Of Critical Infrastructures, Proc. of 4th International Conference of Management and Industrial Engineering (ICMIE 2009), pp: 192-198, Bucharest, 2009

[5] J. G.-Guzmán, F. H. Villa-López, F. H. Silva-Del-Rosario, A. Ramírez-Ramírez, J. Enríquez and E. J. Álvarez-Sánchez, “Virtual environment for remote access and automation of an AC motor in a web-based laboratory”, 2012

[6] K. Langlois, T. van der Hoeven, D. Cianca et al., EtherCAT Tutorial An Introduction for Real-Time Hardware Communication on Windows, IEEE Robotics & Automation Magazine, volume: 25 (1), 10.1109/MRA.2017.2787224, pp 22-27, 2018

[7] M. Barbulescu, O. Grigoriu, G. Neculoiu, O. Niculescu-Faida et al, Energy Efficiency in Cloud Computing and Distributed Systems, Proc. of RoEduNet Conference 2013, ISBN:978-1-4799-2599-5, pp 1-5, 2013

[8] V. Calofir, G. Stamatescu, I. Stamatescu, N. Arghira, S. Iliescu, I. Fagarasan, E.Calofir, Implementation of e-learning concept for industrial control system. A case study, Proc of ELSE2018, Volume 3, DOI: 10.12753/2066-026X-18-145, Pages: 27-3, 2018

[9] I. Stamatescu, G. Stamatescu, I. Fagarasan, N. Arghira, V. Calofir, S. St. Iliescu, ASID: Advanced System for Process Control towards Intelligent Specialization in the Power Engineering Field, Proc. of IEEE IDAACS 2017, Pages: 475-480, 2017

[10] I. Fagarasan, I. Stamatescu,N. Arghira, et al., Control Techniques and Strategies for Microgrids Towards an Intelligent Control, Proc. of IEEE CSCS21, DOI: 10.1109/CSCS.2017.96, pp 630-635, 2017

[11] I. Stamatescu, N. Arghira, I. Făgărăşan, G. Stamatescu, S. St. Iliescu, V. Calofir, “Decision Support System for a Low Voltage Renewable Energy System”, Energies, vol. 10(1), doi:10.3390/en10010118, pp 118-128, 2017

[12] O. Dragomir ; F. Dragomir, Decision support system integrating fuzzy logic and expert system for optimization of smart grid functioning, Proc. of CoDit 2016, pp 1-5, 2016

[13] Opriş, I., Costinaş, S., Ionescu, C.S., Nistoran, D.E.G., Towards augmented reality in power engineering, 2017 10th Int. Symposium on Advanced Topics in Electrical Engineering, ATEE 2017 7905160, pp. 39-44