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 May 2019, Article number 8825609  
 10th National Conference with International Participation, ELECTRONICA 2019; Sofia; Bulgaria; 16 May 2019 through 17 May 2019; Category numberCFP19P58-ART; Code 151781

## Development of Hardware and Software Methods and Tools for a Successful PLC Training

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The implementation of the paradigm Industry 4.0 will be successful when the ubiquitous automation of the industrial processes and equipment becomes a reality. For this purpose the training of future engineers must give them a theoretical knowledge and practical skills in the PLC software development. The paper describes the possibilities of a PLC training simulator and some software examples which are intended for learning the basics of the PLC programming. The learning by doing approach is suggested in order to allow students to master the knowledge step by step which is expected to lead to sustainable results. © 2019 IEEE.

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**Author keywords**

(industry automation) (learning by doing) (PLC) (simulation) (teaching in PLC programming)

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# Development of Hardware and Software Methods and Tools for a Successful PLC Training

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**Abstract** – The implementation of the paradigm Industry 4.0 will be successful when the ubiquitous automation of the industrial processes and equipment becomes a reality. For this purpose the training of future engineers must give them a theoretical knowledge and practical skills in the PLC software development. The paper describes the possibilities of a PLC training simulator and some software examples which are intended for learning the basics of the PLC programming. The learning by doing approach is suggested in order to allow students to master the knowledge step by step which is expected to lead to sustainable results.

**Keywords** – industry automation; learning by doing; PLC; simulation; teaching in PLC programming.

## I. INTRODUCTION

The Industry 4.0 paradigm represents the transformation of the industrial enterprise after the introduction of information and communications technologies. The possibilities for ubiquitous information transfer allow for data acquisition and real time processing which provide information for the working conditions and the status of the equipment. This will support decision making leading to improvement of flexibility, quality, effectiveness and safety of the manufacturing.

Modern industrial control includes the automation of industrial processes and industrial equipment. Recently, based on the significant progress in the semiconductor industry, electronics, computing and telecommunications, industrial control has advanced and obtained new features which have led to autonomous enterprises. Autonomous technologies allow the equipment to work independently once it is programmed.

Automation in the harsh industrial environment requires devices with sustainable and rugged hardware and a reliable software [1]. Programmable logic controllers (PLC) cover most of these requirements and they are used widely in automation tasks solution. The main advantages of their application are [2], [3]:

- Cost-effectiveness in complex systems control;
- Flexibility - can be reprogrammed quickly and easily in order to control other systems;
- Computer capabilities allow for more sophisticated control;
- Integrated development environments make programming easier and reduce downtime;
- Reliability at work in industrial conditions;
- Communication capabilities for connection to computer and other control systems;

- Opportunities for building distributed control systems, industrial information networks and cloud systems.

Hence, there is a need of teaching skilled engineers who will be able to overcome the challenges of the industrial automation. This is one of the main requests of the employers who insist that graduates in the STEM field should have enough theoretical knowledge and practical skills to begin a successful career. Engineering faculties face the task of organizing education in the field by providing relevant subjects and laboratory tools.

The goal of the research presented herein is to develop a reliable electronic system and proper assignments for PLC programming which will enable the sound knowledge of the basics of the automation software development.

This paper is organized as follows: section 2 highlights the application of the simulation in the learning process. The proposed simulator and its possibilities are described in section 3. The conclusions and the future work are presented in the last section.

## II. SIMULATION – AN ESSENTIAL APPROACH OF THE LEARNING PROCESS IN THE STEM FIELD

Simulation and modelling are study approaches which take place in different fields of scientific and application developments. Because of the nature of a specific industrial object or manufacturing process it is impossible for the program adjustment to be performed in real conditions for reasons of security and safety. So, the operation of the hardware and software is verified onto a model of the object first and after possible adjustments they are implemented in the real world. Thus there is a necessity of simulators providing signals with parameters which completely match the ones generated by the object in real conditions. Simulators with such capabilities are used in PLC programming training.

To greater extent simulation and modeling have wide application in training of operators in industry areas like electric power production, chemical manufacture, machine building and etc. where interruption and accident regimes creation for the purpose of training are impermissible. Simulator systems are designed to mimic real-world environments and they can provide a safe and risk-free platform for job training, project testing, design engineering and troubleshooting. The simulator systems allow for:

- Training reinforcement;
- Skill testing;
- System troubleshooting;

- Instrumentation test and calibration;
- Software testing and debugging;
- Back-up spare parts;
- On-the-job training;
- HMI screen development;
- System integration testing;
- Network testing.

Technology and engineering are important parts of the STEM field. In order to provide relevant teaching in this field the Faculty of Electronic Engineering and Technologies at the Technical University of Sofia included a new course entitled “Automated control in the industry” with two hours laboratory work per week in the last semester of the Bachelor in electronics curriculum. A major part of the laboratory work is intended to allow students to develop skills in PLC software development and testing. These skills will be of great importance in their future job if they choose industrial automation as the start of the career.

The verification of software performance is a very responsible task. After a program has been written its performance has to be verified and all possible cases have to be executed before the implementation in production. When the application is simple and not risky, this might involve running the program on the machine, and looking for improper operation. In complex applications this is not suitable. There the simulation approach ensures the conditions for testing. Simulators make it possible for the programs to be tested without the actual machine. The simulator usage typically follows the next basic steps:

- Identification of the machine inputs and outputs;
- Development of a basic model of the system in terms of inputs and outputs, including items such as expected sensor changes, what responses actuators should have, and expected operator inputs;
- A simulator configuration as a combination of specialized software and hardware for modelling a particular system;
- A verification of the simulator performance for the expected operation of the developed system;
- Software testing and operation verification of the developed system using the simulator.

The role of simulation is very important in the learning process in the field of STEM because of the obvious reasons:

- It is not possible that numerous physical laboratory set-ups dedicated to different tasks of automation are ensured;
- An opportunity for designing new laboratory assignments with different extent of difficulty in accordance with students’ level of knowledge;
- Provision of safety conditions for the students.

To develop a simulator which will be in use in the learning process in PLC software design the electrical and functional characteristics of the input and output circuits of the PLC must be specified.

### III. LEARNING ENVIRONMENT DEVELOPMENT

The main feature of the simulator is to ensure the standard voltage levels for the inputs of the PLC and to measure the voltage on its outputs accurately. There is a variety of ranges

for input voltages but the most popular ones are 24 Vdc and 200-240 Vac for the digital inputs and outputs, and -10V to +10V for the analog inputs and outputs.

The course content is based on the PLC of Siemens Simatic S7-1200 CPU 1214C DC/DC/DC with on-board 14 digital inputs and 10 digital outputs, and 2 analog inputs. The input and output ranges for the digital ports are 24 Vdc and +10V for the analog inputs [4]. In order to extend the abilities of the simulator and to make it applicable in work with another PLCs like Simatic S7-200, Simatic S7-300, and VIPA, the number of the digital inputs and outputs has to be increased and the ability to set negative analog voltage up to -10V has to be provided.

#### A. Description of the simulator

The simulator is equipped with 16 digital inputs, 16 digital outputs, 1 analog input, and 1 analog output for general purposes. Also there are provided two digital outputs for testing hardware and software counters with fixed frequency values of 4 kHz and 40 kHz. For studying the BCD to integer conversion there are intended digital switches for setting the value of the decimal numbers in BCD code. The outputs of these switches can be connected to the digital inputs of the PLC. The range of the numbers is from -999 to +999. The integer to BCD conversion will be experimented using 7-segment LED display. In this case the outputs of the PLC set the numbers on the specified digital inputs of the simulator. The block diagram is shown in Fig. 1.

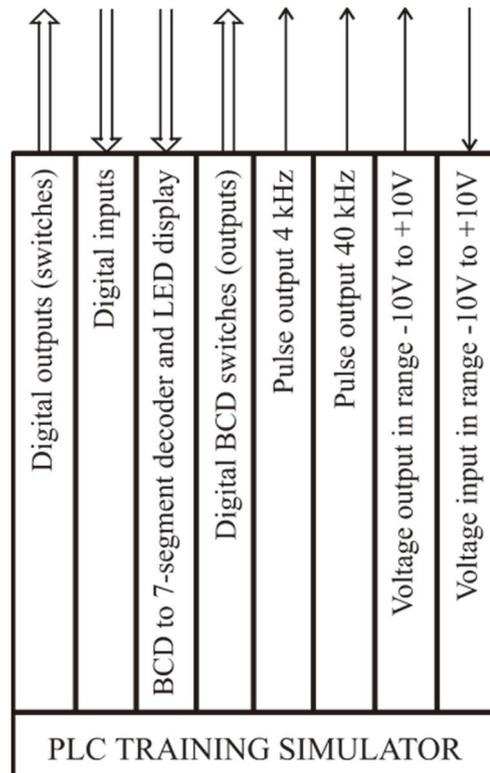


Fig. 1. PLC training simulator

The voltage range for the digital inputs and outputs is 24Vdc. The output level is changed by switches. The states of the digital signals are visualized by LEDs. The analog input and output range is from -10Vdc to +10Vdc. The output voltage is set by a precise potentiometer. Both input

and output voltage are measured by using the digital voltmeter modules DVM 220.

### B. Basic programming examples

The purpose of the teaching process is not only to provide students with knowledge and skills but to convince them of their abilities. The opportunity to control scaled models of real objects gives them self-confidence in their skills and motivates them to study harder. In order to increase the level of difficulty smoothly it is necessary to prepare proper examples. Using the learning by doing approach the students will extend their knowledge step by step which is expected to lead to sustainable results.

The learning process concerns the studying the basics of PLC software development by using the following standard programming languages: LAD (ladder logic) - a graphical programming language, FBD (Function Block Diagram) - a programming language that is based on the graphical logic symbols used in Boolean algebra, and SCL (structured control language) - a text-based, high-level programming language. STEP 7 programming software of Siemens provides a user-friendly environment for development, editing, and monitoring the logic needed to control the user's application, including the tools for managing and configuring all of the devices in the project, such as controllers and HMI devices [4], [5].

The simulator described above provides flexibility in creating different tasks which will give students the possibility to acquire a sufficient set of skills in PLC programming.

The first examples use as a background the basic logic functions which students must have been got acquainted with in the previous semesters - AND, OR, XOR, etc. as it is shown in Fig. 2.

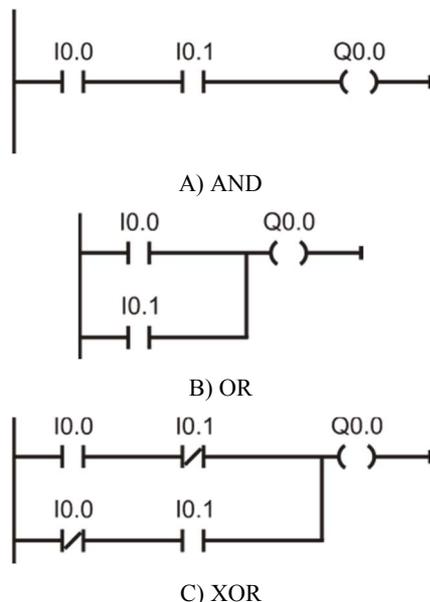


Fig. 2. Basic logic functions realization by using LAD

The simplification of the logic functions by using the De Morgan's theorem is also a suitable teaching matter as it is depicted in Fig. 3. It is obvious that in the realization of the functions NAND and NOR the NOT contact is avoided.

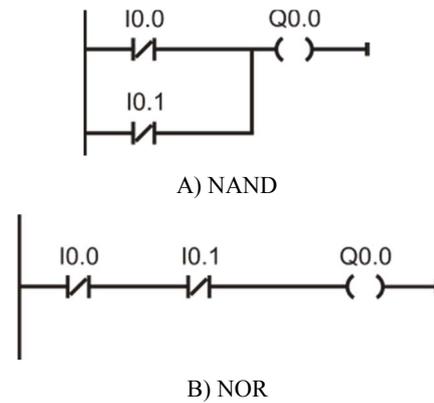


Fig. 3. Application of the De Morgan's theorem for logic functions transformations by using LAD

These examples will help students to remember the laws of the digital electronics and will illustrate their application in industry automation.

A real control application is shown in Fig. 4. The task is solved by using the three languages - LAD (A), FBD (B), and SCL (C). It could be used successfully for motor or lamp control with a PLC. In the following example, a normally open "Start" pushbutton is wired to the first input (I0.0), and a normally closed "Stop" pushbutton is wired to the second input (I0.1). Normally open output Q0.0 contact "On" is also programmed as a sealing contact. With this simple network, energizing output coil Q0.0 is required to turn on the motor or the lamp. The output Q0.0 will stay on even if the "Start" pushbutton is released. When the "Stop" pushbutton is pressed, input I0.1 turns off, the I0.1 contact opens, output coil Q0.0 de-energizes, and the motor or the lamp turns off.

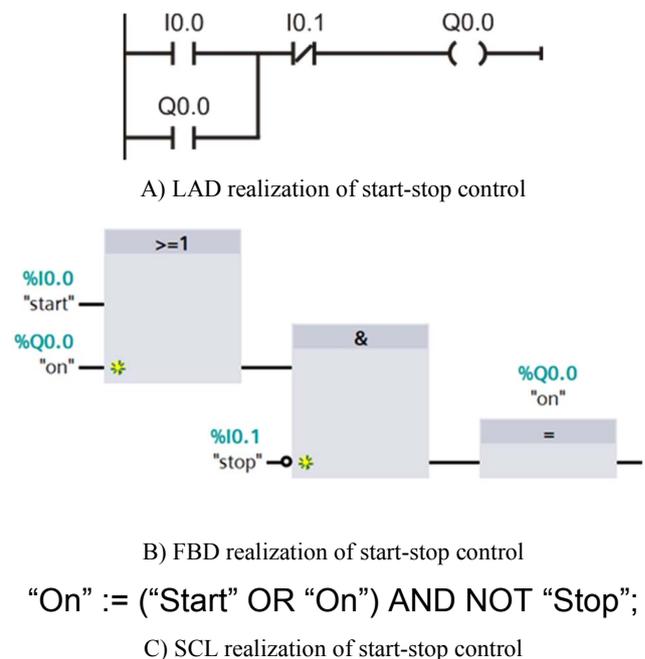
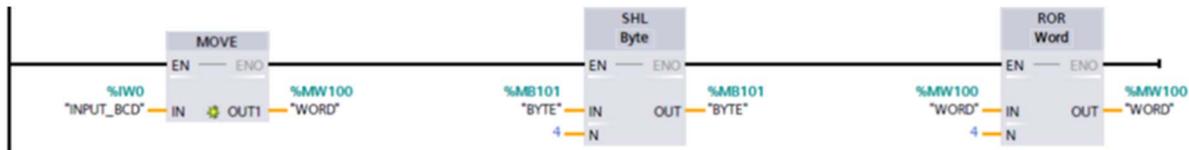


Fig. 4. Realization of start-stop control by using PLC

The next example represents a possible solution of a task for conversion of signed BCD input number to signed integer (Fig. 5). For this purpose are used the BCD switches of the simulator. The range is from -999 to +999. The example demonstrates the usage of box instructions.

Network 1:



Network 2:

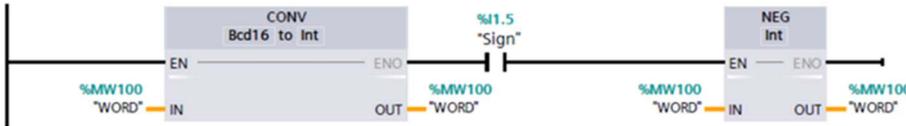


Fig. 5. Conversion of signed BCD to signed integer using box instructions

The BCD switches are connected to the input points as follows: the lowest digit - to the digital inputs from DI b0 to DI b3; the sign input is connected to DI b5; the medium digit is connected to digital inputs from DI a0 to DI a3; the highest digit is connected to digital inputs from DI a4 to DI a7. The program consists of two networks. The Network 1 is intended to position the BCD numbers in consecutive half bytes according to their weight and in Network 2 the BCD word is converted to an integer. In the input scan the states of the input points are stored in two bytes in the Process Image Inputs memory on addresses IW0 and IW1. In the logic scan this information is moved as a word to the Bit memory (M) on address MW100. The next two instructions shift and rotate the bits in order to set the half bytes consecutively in the lowest 12 positions of the word clearing the highest 4 bits. After that the BCD word is converted to integer. The last instruction sets the sign of the integer according to the input.

The student's workplace for PLC training including the developed simulator and a PLC of Siemens Simatic S7-1200 is shown in Fig. 6.

#### IV. CONCLUSION

The paper considers the main objectives of the implementation of a PLC simulator in the teaching and learning process in automation software development. This simulator allows for a step by step study of PLC software by using the learning by doing approach. It provides flexibility in the development of cases for studying the different instructions of standard programming languages LAD, FBD and SCL. It is expected that the developed hardware and software approaches and tools will lead to a successful education in the STEM field which will allow graduate engineers to start their career in industrial automation.

#### ACKNOWLEDGMENT

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

#### REFERENCES

- [1] Zhang, Peng. Industrial control technology: a handbook for engineers and researchers. William Andrew Inc., Norwich, NY, USA, 2008, ISBN: 978-0-8155-1571-5.
- [2] Jack, H. Automating Manufacturing Systems with PLC-s, (Version 5.1, March 21, 2008), Copyright (c) 1993-2008 Hugh Jack (jackh@gvsu.edu).
- [3] Hughes, T. A. Programmable Controllers, Third Edition. ISA – The Instrumentation, Systems, and Automation Society, 2000, 334 p.
- [4] Siemens AG, S7-1200 Programmable controller. System Manual. V4.2, 09/2016, ASE02486680-AK.
- [5] [www.industry.usa.siemens.com/services/us/en/industry-services/services-glance/training-services/Pages/training-services.aspx](http://www.industry.usa.siemens.com/services/us/en/industry-services/services-glance/training-services/Pages/training-services.aspx).

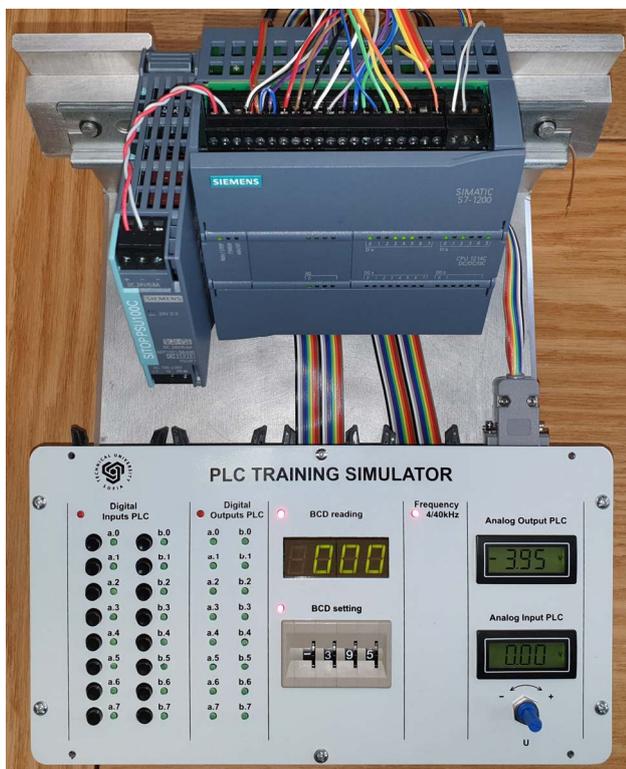


Fig. 6. Student's workplace for PLC training