Abstract - Programmable logic controllers' (PLC) State simulator is a device which simulates active operating area (workspace) while testing executive program loaded in PLC's memory.

PLC is connected with State simulator we developed and PC compatible computer. After testing and verification of program code accuracy, program implementation in that workspace is possible simply by wire connection to input/output slots on the State simulator and connectors of the external device or process. Main advantages of this State simulator are: output discrete state display in binary and BCD code, analog values measurement from PLC's D/A converter, discrete input state defined in binary and BCD code, analog values defined towards PLC's A/D converter.

PLC simulator we developed is to be used in research and testing of program code for applications in automation of plants and processes. We apply this simulator in laboratory exercises at Polytechnic of Zagreb.

I. INTRODUCTION

Industrial processes are usually controlled with relay logic based systems. Relay logic hardware, as a basic of control systems, is very inflexible because the change of control function requires the change of firmware. Microprocessor development allowed construction of industrial computer control system which could change functions by changing program code. PLCs' appearance showed many advantages in relation to relay control system.

PLCs' development and intense usage in industry encouraged a need for quality educated engineers who can define and solve problems within boundaries of new technology. Need for importing didactical approach in teaching resulted in combining PLCs with State Simulator.

II. PROBLEM'S APPROACH

PLC's State Simulator is a device which simulates active operating area while testing executive program loaded in PLC's memory.

State simulator's goal is to confirm written program code's accuracy i.e. executive program performing in active operating area (workspace). It is especially important while program implementation in such workspace where false program execution can cause huge damages.

PLC is connected at the same time by its digital and analog inputs and outputs with State Simulator (while testing accuracy or changes in program) and by serial connection with main computer where program code is entered and sent to PLC (Figure 1).

![Figure 1. Device connecting block scheme](image)

PLC devices regardless size have the same hardware in general: input (digital and analog inputs), output (digital and analog outputs), CPU, memory block for program and data, firmware power supply, communication interface and extension modules (Figure 2).

![Figure 2. PLC's block scheme](image)

While considering executable solution, one was chosen with possibility of displaying and setting discrete states of inputs and outputs in binary form and BCD code. Then there was a need for displaying and measurement of analogue voltage values from referent power supply, which can be measured with installed digital voltmeter. So, conclusion was made that PLC's State Simulator must have these characteristics:
• output discrete condition display in binary form
• output discrete condition display in BCD code
• analog values measuring from PLC's D/A converter
• input discrete condition defining in binary form
• input discrete condition defining in BCD code
• analog values defining towards PLC's A/D converter

Device was to be made so that it can function with any type of PLC, regardless of model or manufacturer, within set analog values range. Also, device reliability was expected during prolonged period of usage, so conditions of intensive exploitation in laboratory with students and adaptability of program testing and executing were taken into account.

III. DEVELOPMENT

PLC's State Simulator is made by components as follows (Picture 1):

- metal box with console for PLC's and State Simulator's montage
- contacts to connect PLC's discrete inputs/outputs
- contacts to connect PLC's analog inputs/outputs
- front panel with elements for process simulation
- BCD code decoder with direct display sensing
- stable referent voltage source
- two analog outputs adjustable in two voltage ranges (0 to +10V, -10 to +10V)

It is necessary to make several stabilized DC sources of different voltages for all interior supplied electronic modules. Supply module is divided in two units: network unit on the box (input euro connector, box fuse, 2 pole switch with network voltage indicator and toroid transformer), and electronic components on shared printed circuit board. Supply integrated serial stabilizers of 7800 and 7900 series and supply integrated serial stabilizers with ability of output voltage adjustment (LM317 and LM337 series) are used in component circuits.

For PLC's discrete input simulating toggle buttons are used (Picture 2) which are located on front panel as a special unit. Interior power supply is used and current is limited (except for the small contact resistance) with interior PLC's resistance. It is possible to define up to 16 discrete PLC's inputs. Marks are assigned for every Simulator's output according to input mark on PLC (e.g. I:0/1).

By moving toggle button to the right PLC's highlighted input is set to the high condition (+24 Vdc). Discrete outputs are made for exterior connections towards PLC on BIN connector (DB37) on the back panel of the State Simulator's box.

For simulating discrete outputs from PLC i.e. high condition indication LEDs are used. State Simulator supports up to 16 discrete inputs, so it is possible to display up to 16 PLC's output conditions at the same time (Picture 3). Due to voltage difference of the PLC's output active high condition and LED's operating voltage, serial advance resistance is estimated. LED's operating condition i.e. output's high condition is supplied directly from interior power source. Current of one output is limited to 7mA by advance resistance.
Marks are assigned for every Simulator's input according to output mark on PLC (e.g. O:0/1). Discrete inputs are made for exterior connections towards PLC on BIN connector (DB37) on the back panel of the State Simulator's box.

To define number in BCD code from State Simulator towards PLC thumb switches are used. Set value is directly displayed on a switch's digital display (Picture 4).

Display of analog output values from PLC is possible on a State Simulator's digital voltmeter. One of two display inputs is selected with input selector. Voltmeter's measuring range (span) is ±19.99V.

Digital voltmeter uses State Simulator's interior power supply. Connections for measuring voltages inputs (IN 1 and IN 2) are located on a front panel with a 1-pole 4mm ports (Picture 6).

Analog values setting from State Simulator towards PLC is possible with two analog outputs. Any of two outputs can be set to two voltage ranges independently:

1. range 0 to 10.5V
2. range ±10.5V

Range selection is possible by switching toggle buttons, which are located to the right of the output 1-pole 4mm ports.

On a block scheme (Figure 3) conversion of BCD output is shown: 4 digital PLC outputs (1) are brought to State Simulator on a BCD/7segments converter (2), which on it's output has a driver for a 7segments display (3).

From the block scheme can be seen that for display of all 4 digits 16 digital PLC's outputs are needed (Picture 5).
Value adjustment within the range is performed by potmeter rotating (of the wanted output). Potmeters are located on the front panel to the right from digital voltmeter's input selector, on which set analog output values can be viewed (Picture 7).

IV. RESULTS

The idea for creating this kind of device appeared in 2000., when course of programming industrial computers started. For the first time State Simulator was used in educational purposes in academic year 2002/03 and since then it's efficiency has been monitored.

Since importing State Simulator in classes, two parameters related to working with students have been monitored – average exam grade per generation and number of students' exam attempts. Data of all students in the course was taken into account; two student generations before importing State Simulator in education and two generations afterwards (Table 1).

Table 1. Average exam grade and average number of students' exam attempts in academic years

<table>
<thead>
<tr>
<th>Academic year</th>
<th>Number of students per year</th>
<th>Average exam grade</th>
<th>Average students' exam attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000/01</td>
<td>115</td>
<td>3,19</td>
<td>2,86</td>
</tr>
<tr>
<td>2001/02</td>
<td>112</td>
<td>3,24</td>
<td>2,63</td>
</tr>
<tr>
<td>2002/03</td>
<td>121</td>
<td>3,46</td>
<td>1,82</td>
</tr>
<tr>
<td>2003/04</td>
<td>118</td>
<td>3,37</td>
<td>1,54</td>
</tr>
</tbody>
</table>

Average exam grade and average number of students' exam attempts were calculated as follows (1):

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

Average exam grade per generation has slightly increased after importing State Simulator in education (Figure 4).

It can be easily explained; better working conditions enabled demonstrating more examples than in the past years and more quality course presentation. Therefore, after importing State Simulator in education, exam criteria increased so average grade increment is slight.

Second monitored value is average number of students' exam attempts per generation (Figure 5).

![Figure 5. Students' exam attempts per academic years](image)

Figure 5. Students' exam attempts per academic years

Importing State Simulator in education resulted in decreased number of students' exam attempts, as shown on the chart. It proves generations that attended classes in a new way solved course problems easily and rather easy passed exam.

V. CONCLUSION

Present massive application PLCs owe to their flexibility, serviceability and acceptable price. Educating about these new technologies on a professional technical colleges demands courses adopting and constructing new educational devices. In this paper professional and scientific approach of such a device constructing and implementation was shown. Except on a colleges State Simulator was implemented in industrial design and maintenance departments (of plants and processes). Plenty of courses for employees in industry have been held at Polytechnic of Zagreb.

Efficiency in program testing written for PLC was improved, written code quality is great because all the program changes are tested on a State Simulator as a test device which replaces real process.

Simulator designing and construction project was started because there was nothing suitable on the market. The goal was to ease education process and help students in solving complex courses on real systems. Expected progress by importing State Simulator in education was accomplished and proven with reduced number of students’ exam attempts.

In cooperation with Department for education our device implementation and teachers training was started in technical schools.

Device can be expanded with additional analog signal simulations and connections of real automation elements.
REFERENCES