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The evolution of PLCs in the light of case studies

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Abstract

After the introduction of eight-bit processors in the late seventies, microprocessor-based industrial process control using home-grown hardware and software gained tremendous momentum despite restrictions imposed by Soviet-influenced countries. Control solutions have been developed for various areas, including comprehensive control of railway interlock systems. I will show the differences in case studies, how PLC systems perform similar tasks these days, and point out the more interesting similarities that exist. The main objective is to use these results for PLC training of mechatronics students at the Faculty of Mechanical and Safety Engineering, University of Obuda. These can greatly help students understand how a PLC can be used and learn how to program it.

Keywords: PLC process control, PLC programming, Centralized railway traffic management

1. Tasks of remote-monitoring / remote-control systems in general

A remote-control/remote-monitoring industrial process control system always includes one or more remotely controlled/monitored local devices, which are operated in parallel to collect local process information. The local equipment may also have certain automatic functions.

A remote-control/remote-monitoring system always includes a database-like information aggregation and storage area containing the operational and status information collected about the system. This can be implemented in the cloud or in the memory of a specific, fixed computing unit.

The system may also include one or more remote computer operator workstations from which all local equipment of the entire system can be monitored/controlled. An operator workstation may be established close to the local equipment if required, but this will normally only allow remote control of the local equipment. These operator workstations may be implemented on dedicated hardware, depending on the design, or on any client PC with appropriate privileges.

The remote-control system greatly facilitates and assists the work of the operator workstation staff by providing various automatic or intuitive prompts and syntactic control of the technology. Other important functions include monitoring operational events, alerting operators when necessary, and recording and printing several different operating logs.

Another important part of the system is the data communication path, which allows bidirectional data transmission between the local equipment and the operator/control centers.

1.1 System GVM-85

Based on the I8085A microprocessor, GVM-85 was a modular microcomputer designed for process control purposes. Within this field, it was universal, just like today's PLCs.

As a result of its lower level of integration, it was made up of many more modules than today's PLCs. It also performed tasks that would be impossible to perform with PLCs today.

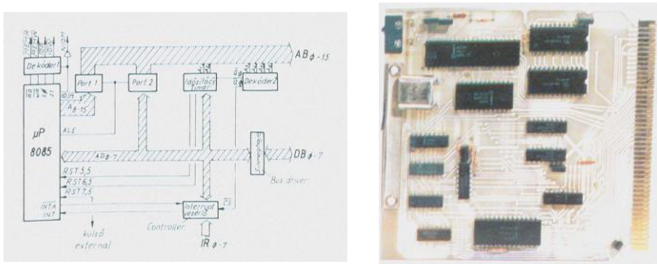

Figure 1. The CPU module of GVM-85 [1]

The hardware was based on the latest 8-bit chipset available from Intel at the time. The CPU module also contained the I8253 timer and the I8259 interrupt control circuitry.

The MEM 24K memory module contained 8 2 KB RAM or EPROM modules, depending on the configuration. The EPROMs had to have the machine code of the control program burned into them before the connection. The bus system ("motherboard") was connected to its own peripheral interface modules, such as the display controller and keyboard port module, matrix printer interface unit, etc.

A maximum of four microprocessors could be interconnected to form a multiprocessor system, using I8255 programmable peripheral circuits (IPC) to allow simultaneous data exchange between processors.

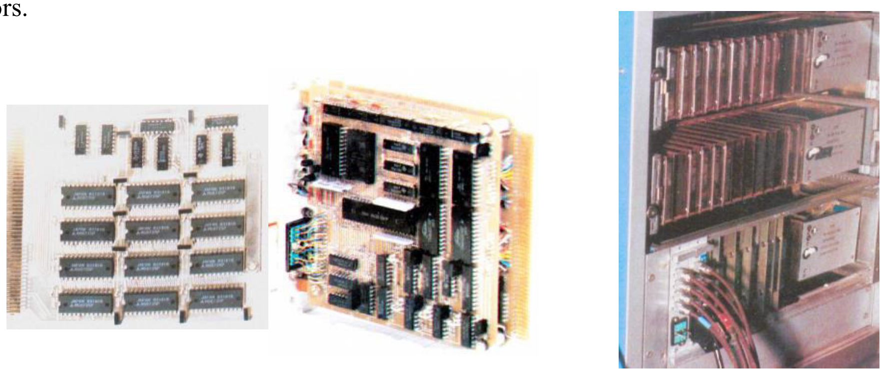

Figure 2. A memory and a display/keyboard/printer module. A cabinet with standardized racks [1]

The digital inputs and outputs were used to scan the digital sensors of the controlled process and to control the actuators (relays, lamps, digitally controlled writing devices). The theoretical maximum configuration was 6570 digital inputs and 2520 digital outputs.

A serial data transmission control unit based on the 8251A USART circuit enabled serial full-duplex MODBUS-type data communication between two or more remote microcomputers. The system also included analogue input and output cards in several versions. [1]

1.1.1 Program development, testing

The program development and structure were done on an engineering workstation composed of system components, using assembly-level language, and system status bits/words (wtd). Source code has been provided by a custom compiler and linker, and it was loaded into EPROMs (See MEM 24 modules).

The program could have been tested using only the "bit-hunting" method.

1.1.2 Applications, projects implemented

Some implemented projects using this system

Industrial process control: automated control of glassworks, waterworks, wastewater treatment plants, wastewater elevation spots

Railway applications: South-Balaton railway line Szabadbattyán – Nagykanizsa section centralized traffic control, Ferencváros station rolling stock automation, Sopron-Ebenfurt railway line electric traction substations, overhead supply switchyard remote control, several other energy remote control systems, Hatvan railway station code control system, Budapest, Batthyány tér - Békásmegyer urban railway line section, centralized traffic control (KÖFI).

The latter will be one of the systems of our case studies.

1.2 Siemens S7-1200 programmable logic controller (PLC)

Today, there is a huge range of process control PLCs available to engineers. In this paper, we will look at the compact design PLCs of the S7 series from Siemens, which were released in 2010. Their application is greatly facilitated by the available TIA Portal engineering development tool.

1.2.1 S7-1200 system components, hardware architecture, configuration options

The CPU unit is a 32-bit microprocessor with digital and analogue inputs and outputs of varying quantity and design. The user program may include logic instructions, mathematical operations, counting and timing tasks, and data link management. Safety and protection functions are also available during PLC configuration to meet today's requirements.

Feature		CPU 1211C	CPU 1212C	CPU 1214C	CPU 1215C	CPU 1217C
Physical size (mm)		90 x 100 x 75		110 x 100 x 75	130 x 100 x 75	150 x 100 x 75
User memory	Work	50 Kbytes	75 Kbytes	100 Kbytes	125 Kbytes	150 Kbytes
	Load	1 Mbyte		4 Mbytes		
	Retentive	10 Kbytes				
Local on-board I/O	Digital	6 inputs/4 outputs	8 inputs/6 outputs	14 inputs/10 output		
	Analog	2 inputs			2 inputs/2 output	
Process image size	Inputs (I)	1024 bytes				
	Outputs (Q)	1024 bytes				
Bit memory (M)		4096 bytes		8192 bytes		
Signal module (SM) expansion		None	2	8		
Signal board (SB), Battery board (BB), or communication board (CB)		1				
Communication module (CM) (left-side expansion)		3				
High-speed counters	Total	Up to 6 configured to use any built-in or SB inputs				
	1 MHz	-				Ib.2 to Ib.5
	100/¹80 kHz	Ia.0 to Ia.5				
	30/¹20 kHz	–	Ia.6 to Ia.7	Ia.6 to Ib.5		Ia.6 to Ib.1
	200 kHz³					
Pulse outputs²	Total	Up to 4 configured to use any built-in or SB outputs				
	1 MHz	–				Qa.0 to Qa.3
	100 kHz	Qa.0 to Qa.3				Qa.4 to Qb.1
	20 kHz	–	Qa.4 to Qa.5	Qa.4 to Qb.		–
Memory card		SIMATIC Memory card (optional)				
Real time clock retention time		20 days, typ./12 day min. at 40 degrees C (maintenance-free Super Capacitor)				
PROFINET Ethernet communication port		1			2	
Real math execution speed		2.3 μs/instruction				
Boolean execution speed		0.08 μs/instruction				

Technical data		SM 1223 DI (24 VDC) / DQ (Relay)	SM 1223 DI (24 VDC) / DQ (24 VDC)
Article number		DI 8 / DQ 8: 6ES7 223-1PH32-0XB0 DI 16 / DQ 16: 6ES7 223-1PL32-0XB0	DI 8 / DQ 8: 6ES7 223-1BH32-0XB0 DI 8 / DQ 8: 6ES7 223-1BL32-0XB0
Number of inputs / outputs (DI / DQ) See specifications (Page 384).		• Inputs: 8 or 16 (24 VDC) • Outputs: 8 or 16 (relay)	• Inputs: 8 or 16 (24 VDC) • Outputs: 8 or 16 (24 VDC)
Dimensions W x H x D (mm)		• DI 8 / DQ 8: 45 x 100 x 75 • DI 16 / DQ 16: 70 x 100 x 75	• DI 8 / DQ 8: 45 x 100 x 75 • DI 16 / DQ 16: 70 x 100 x 75
Weight		• DI 8 / DQ 8: 230 grams • DI 16 / DQ 16: 350 grams	• DI 8 / DQ 8: 210 grams • DI 16 / DQ 16: 310 grams
Power dissipation		• DI 8 / DQ 8: 5.5 W • DI 16 / DQ 16: 10 W	• DI 8 / DQ 8: 2.5 W • DI 16 / DQ 16: 4.5 W
Current consumption	SM Bus	• DI 8 / DQ 8: 145 mA • DI 16 / DQ 16: 180 mA	• DI 8 / DQ 8: 145 mA • DI 16 / DQ 16: 185 mA
	24 VDC	4 mA / input used 11 mA / Relay coil used	4 mA / input used

Figure 3. Different S7-1200 type PLC versions and some of I/O extension modules [7]

Figure 4. An S7 1200 PLC configuration: power supply, CPU 1214C DC/DC/DC, digital input and output extension modules

1.2.2 Data transmission, communication

All CPU units of the S7-1200 PLC family include a PROFINET connection for network communication (Ethernet, programmable IP address) and can be easily extended by up to 3 x 3. RS 485 or RS 232 communication units.

1.2.3 State visualization options

The HMI is the tool for process state indication in the PLC environment. Its configuration and programming are greatly supported by the TIA Portal development system.

The web server service of the PLC is a practical feature of the S7-1200 family that can be configured by the user for on-site testing or for remote monitoring/remote control.

Figure 5. Status visualization by an HMI unit or by using web server feature [6]

Of course, there is also a wide range of licensed SCADA (Supervisory Control and Data Acquisition) programs specifically designed for remote control and monitoring. Based on a system database, these allow the use of different kinds of easy-to-configure visualization and system management.

1.2.4 The TIA Portal engineering tool for program development

Developers can use TIA Portal to perform the complete system design of a project, from the definition of the hardware and network configuration and HMI interfaces, through the writing, testing, and operational simulation of the user software and HMI display, to the online diagnostics check after download.

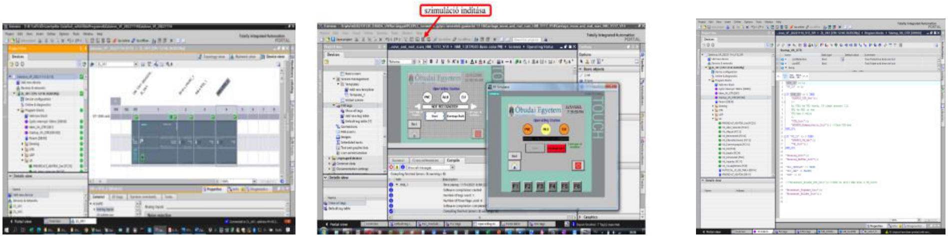

Figure 6. Some of the functions of TIA Portal engineering tool

When programming, standard program languages can be used according to IEC 61131-3. By writing organizer blocks (OB), function blocks (FB) and functions (FC), or by using standard FBs and FCs, and by defining the necessary data blocks (DB), user programs can be written in a very well-structured way, using status words along the system steps for cyclic or single sequence controls. [8]

The PLC web server service, configurable through the TIA Portal, helps to monitor real operation on the fly.

2. Case study: urban railway line, centralized traffic supervision and control

The system controls the section from station Batthyány tér to station Békásmegyer of a busy urban railway line, with trains running every five minutes at peak times.

On the double-track railway line, three directly interconnected railway interlock systems have been built (belonging to stations Batthyány tér, Aquincum, and Békásmegyer). In order to simplify and automate the handling operations, trains are generally operated by means of automatic signaling.

Parts of the centralized control system are the Interlock Controller Equipment (ICE) of each station interlock system, the data transmission line, and the Central Control Room (CCR). (*see Figure 7.)*

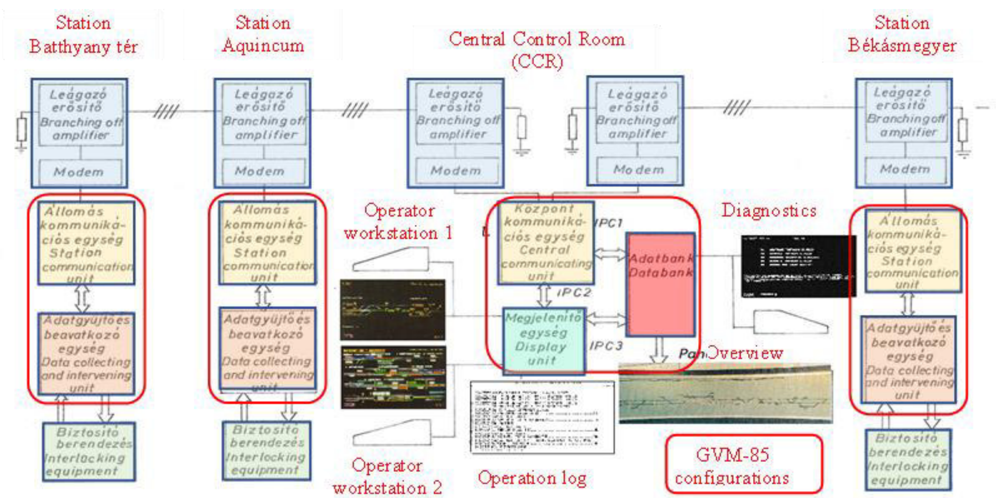

Figure 7. The structure of the centralized control system [3]

2.1 The ICE of the railway section interlocks

Each ICE is of a dual-processor "GVM-85". These communicate with the central equipment by means of a serial MODBUS kind four wire voice-frequency connection. They do data acquisition, collecting input status information from the station interlock system (623/984/820 digital inputs of interlocks, respectively) and transmit these states to the control center. In remote control mode, they interpret the commands sent by the control center and execute them on their connected interlock system using 134/266/159 relay outputs, respectively, in a controlled manner.

The data is exchanged via a parallel communication channel (IPC) between the two processors of the ICE.

2.2 Central control

The CCR equipment is a configuration of a three-processor GVM-85. Tasks of its units are to manage the communication with the ICEs, to serve as a databank, and to visualize the interlocks states for the operators and receive their commands on the workstations. The units, each with a processor in charge, communicate with each other in parallel, as each of them is directly connected to the others.

The communication unit is responsible for organizing the data transmission and the physical management of the two MODEMs connected to the serial voice frequency lines. The MODBUS-like communication is achieved by asynchronous, phase-modulated MODEMs via full duplex data transmission. The communication unit collects the data from the ICEs and transmits the operator commands to them.

The databank of the CCR equipment contains direct physical information, but various logically calculated or generated information as well, such as the communication and hardware status of each station, or train numbers from the visualization unit. It controls the lamp lights of the huge overview wall as well. The diagnostic module is also part of this unit. This allows to monitor the operation of the system, to isolate a possible fault.

The visualization unit of the CCR duties includes serving traffic control workstations and generating the printed operation log. The traffic control workstations are uniform in design. Each workstation is equipped with a color, semi-graphic monitor and a keyboard. The entire line can be controlled from any of the traffic control workstations. [3]

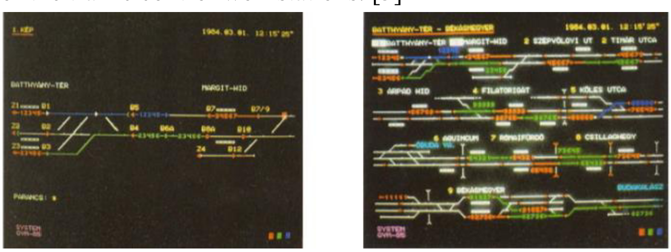

Figure 8. Status visualization examples at the CCR [2]

3. Case study: LINE SECTION Zalacséb-Salomvár - Őriszentpéter REMOTE CONTROL OF Railway switch HEATING CIRCUITS

The Hungarian Railways Co. (MÁV Zrt.) recently replaced the gas-powered switch heating system at the Zalacséb-Salomvár, Zalalövő, and Őriszentpéter stations with an up-to-date electric heating system, which prevents the formation of snow and ice coatings near the moving parts of the switches, which would hinder safe operation.

3.1 Local switching area control units (ACUs)

At railway stations along the line, local railway switch areas (RSA) were created depending on the spatial location and the power supply possibilities. Each RSA is equipped with a local area control unit (ACU) driven by a PLC for data collection and intervention.

The ACU is installed in a conveniently located modular outdoor cabinet, which is easy to configure and contains all the power switching, protection, and disconnection components for heating of the zone's railway switches as well as the necessary interface for the temperature control devices.

The ACU is the basic unit of the system, which can operate independently and does not require any intervention in automatic mode. Based on the temperature of a heated and a cold rail and information from intelligent meteorological sensors (air temperature, precipitation, etc.), it switches the circuits of the associated heating filament according to a programmed algorithm. It also continuously checks the status of other operating controls and monitoring elements, switches, sensors, and meters. The PLC of the ACU also includes appropriate graded procedures based on a data communication link with adjacent ACUs for the case of meteorological sensor failure.

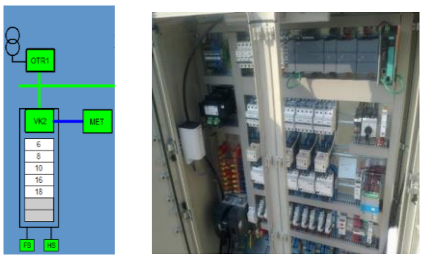

Figure 9. SCADA visualization and the cabinet of an ACU [4]

The electrical power supply of the RSAs heating is provided from the traction 25 kV, 50 Hz network, from 25/0.230 kV transformers. The power for ACUs is supplied via 230V/24V through its uninterruptible power supply (UPS) unit. For the heating of the RSAs at Zalalövő railway station, there are two ACUs, at Zalacséb-Salomvár, one, and at Őriszentpéter, three of them are in charge.

3.2 On-site commissioning options using PLC web server, monitoring, and control

The PLC web server function is a very useful feature for testing the operation of ACUs. This allows with the appropriate privileges via the Internet access to the PLC web server. This has been pre-customized and downloaded to the PLC by the TIA Portal engineering tool.

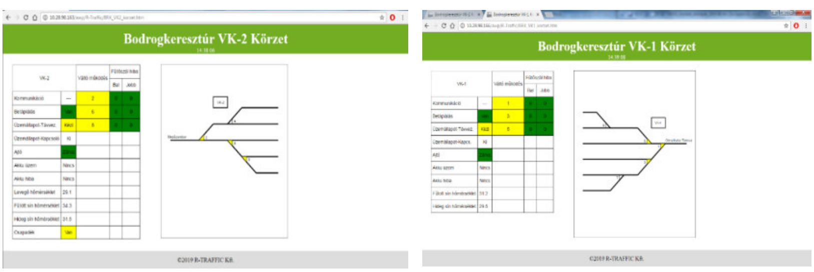

Figure 10. Status display through the web server

3.3 Remote monitoring and management with SCADA

Remote system monitoring and remote control of Zalalövő and the two adjacent stations happen to be settled in Zalalövő station and in the so-called FET center of the MÁV Directorate in Szombathely. For this purpose, a client computer runs a SCADA system, which is used for remote monitoring and remote control of the switch heating systems of the stations of the line section.

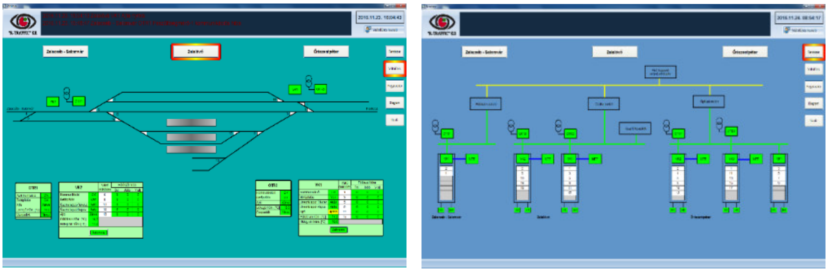

Figure 11. SCADA overview and railway switch heat visualization on the remote monitoring / remote control workstation [5]

3.3.1 Railway switch heating view

The SCADA program allows viewing all the input information of the system, displaying the status of any of its elements, and switching on and off the heating of any railway switch of the ACUs in this view. It provides a number of services based on the "operating log" continuously recorded in the dedicated storage of the system.

3.3.2 Consumption measurement, diagrams, log windows

The energy distribution part of the railway switch heating system is equipped with a separate digital meter. The measured data can be read by PLCs and displayed on the control interface for each ACU.

The diagram windows show the diagrams of analogue signals and meter values like the phase currents, phase voltages, temperatures (air, heated rail, cold rail) associated with each zone. By analyzing them, operations engineers can obtain information on how the external factors affect the operation over time.

Logs can be classified in a lot of different ways, but they have a uniform display layout. Some functions apply to all logs, but there are also log-specific operations. All signals and operational intervention events are included in the logbook if they are defined in such a way that their occurrence or change has logging consequences.

Figure 12. Further SCADA services [5]

3.4 Data transmission

The system's ACUs and the Zalalövő traffic office management device are connected to the remote monitoring and control system via an optical Ethernet network. The data transmission between the particular ACUs and the headquarters in Szombathely is carried out via the Intranet network of MÁV, their addressing complies with the rules for the VLAN network of the heated switches.

This structure allows remote management and control of the system elements from anywhere and at any time, but it’s subject to the appropriate authorizations and the limitations built into the technology, of course.

4. Conclusion

Table 1 shows a comparison of the system components of the above example systems. It is obvious that the developments and changes in the technological background over the last four decades have greatly facilitated the work of system design engineers and have greatly increased the level of service of the process control systems that can be created.

A more detailed examination of the above example systems also shows that the conceptual design of the two main pillars of these remote-control systems, which are distant in time but typical in their time, is very similar:

- Today's process control systems are built from virtually identical functional system components as their roughly 40-year-old predecessors. The way the controlled system and the process control are connected is identical (galvanically isolated DIO, AIO)
- The organization of the system control programs in today's typical process control systems is carried out in the same way along the different states of the system, using status bits/words, as it was at the dawn of computer process control.

To sum up, despite the accelerated technical-technological development, the theoretical considerations of the solutions applied to process control systems have proven to be timeless in the long run, providing a stable and well-tested basis for the education of engineering students who will be working on industrial processes.

5. Table

Table 1. System comparison table

System component	Siemens S7-1200 PLC	GVM-85
Architecture of the remote control system	Communication controller, database, operator workstation(s) Field/station units, (data collection, intervention, communication) Data transmission path	Communication controller, database, operator workstation(s) Field/station units, (data collection, intervention, communication) Data transmission path
System and hardware configuration design	Fast, easy to learn	Thorough system knowledge required
Program management	State-driven	State-driven
System development tool	TIA-Portal Standardized programming languages	None. Assembly level programming, slow and cumbersome
Commissioning, testing	entire toolbox of TIA_Portal , simulation	Device-dependent, slow, difficulty in making program changes
Safety	Hardware design TIA_Portal supported authorization system	No real protection, just the special architecture, it's all up to the programmer
Extensibility	Flexible, easy to extend	Bound but modular architecture, can be extended by programming
Data collection and intervention units	Galvanically isolated DI/O, AI/O	Galvanically isolated DI/O, AI/O
Operator workstation, visualization	Graphical, high-resolution, modern, object-oriented architecture	Pixel-level, character graphical, hand held programming
Databank	Dedicated computer, possibly cloud	Dedicated computer
Logging, archiving	SCADA	Printed, implemented by programming
Data transmission	Optical network, TCP/IP	Wired, MODBUS-like

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