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AUTOMATIZIRANO UPRAVLJANJE CRPNOM STANICOM

AUTOMATION OF SEWAGE PUMPING STATION

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Stručni članak

Sažetak: *U ovom članku opisan je princip rada crpne stanice kanalizacijskih okna kao primjer automatiziranog pogona s distribuiranim upravljanjem i nadzorom. Izvedbeni prototipni model koristi se za izradu, provjeru i unaprjeđenje programskog koda i za vizualizaciju sustava (SCADA sustav). Prikazana metodologija može se koristiti pri razvoju bilo kojeg automatiziranog pogona gdje se traži od upravljačkog sustava povećanje produktivnosti i praćenje stanja crpne stanice i cijelog operativnog sustava. Na jednostavnom primjeru crpne stanice moguće je prikazati implementaciju digitalne upravljačke jedinice na mjesto relejne tehnike malog pogona, te bežičnu komunikaciju s dislociranim uređajem za sučelje prema operateru.*

Ključne riječi: *automatizacija, crpna stanica, PLC (programabilni logički kontroler), SCADA (Supervisory Control And Data Acquisition), TIA Portal*

Professional paper

Abstract: *In this paper the main principle of sewage pumping station shaft is described as an example of automated facility with distributed control and supervision. The prototype design station is used for producing, testing and improving program code and system visualization (SCADA system). Methodology presented in this paper can be used in the development of any automated system where it is necessary for control system to ensure increased productivity and supervision of the system state. On a simple example of a sewage pumping station it is possible to present the implementation of digital control unit instead of relay technology in a small facility and wireless communication with dislocated device for human-machine interface.*

Key words: *automation, pumping station, PLC (Programmable Logic Controller), SCADA (Supervisory Control and Data Acquisition), TIA Portal*

1. INTRODUCTION

Today mechanical systems cannot be examined, planned, projected and monitored without constant insight into the system state. Relay control technology was sufficient for ensuring correct operation and reliability of the system, but problems appeared during the development and monitoring of such systems. With time it was recognized that every change in functionality required a long and laborious wiring substitution that is very susceptible to errors. Furthermore, it was very difficult to gain insight into the parameter status and the physical quantities of the system that was, in the best case, physically dispersed on several locations.

By introducing central control systems based on computers and microcontrollers, significant simplifications of operation and maintenance of such systems have been implemented. This paper describes an example of introducing SCADA subsystem into the drainage system with pumping stations, which structurally relies on the research of implementation of a digital control system described in [1], [2] and [3].

2. STATE OF THE ART

For the selection and configuration of the control system and the compilation of programming solutions of a digital control system one should be familiar with mechanical characteristics of the plant along with all influences that are of crucial importance for normal operation of a station. A prototype pumping station model should contain all relevant characteristics of a pumping station for the purpose of projecting, constructing and upgrading the possibilities related to control and monitoring.

2.1. Programmable logic controllers

The development of digital computers during the 1950s and 1960s encouraged the substitution of relay technology by digital control units. Computers completely replaced relay technology and simultaneously eliminated their downsides. The requirements posed to digital control units are simple programming, simple error detection in the program, simple maintenance and reliable operation in industrial conditions.

At the end of the 1960s the Bedford Associates Company produced the Modular Digital Controller (MODICON) as the first commercial PLC. Programming using the first PLCs was similar to drawing a relay connection scheme. In the 1970s, as processors were developed, PLCs became more powerful. Time assemblies, counters and possibilities of performing arithmetical operations were added. The possibilities of connecting PLCs through communication networks and processing analog process signals also appear. In the 1980s program packages appeared, which allowed for programming PLCs from personal computers instead of manual programming devices or terminals anticipated for this purpose. In the 1990s standardization was introduced (IEC 61131, EN 50170) regarding the programming languages for programming PLCs, instruction lists, functional block diagrams and ladder diagram. Since the year of 2000 the development of programming possibilities has slowed down and the progress of communication technologies has been highlighted.

The main PLC parts are processor (CPU), memory, inputs and outputs [4]. Furthermore, there are auxiliary parts that are in charge of good interaction of basic PLC parts. These are the bus, power supply module, communication part and possible additional modules for expanding the basic configuration. The basic PLC structure is shown in Figure 1.

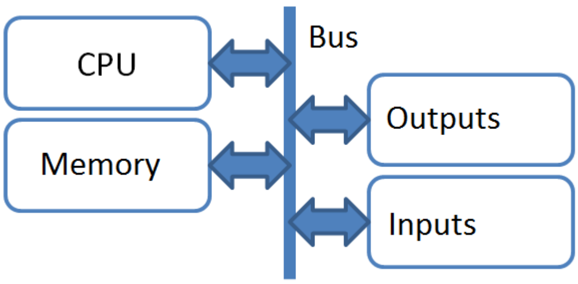

Figure 1. PLC scheme [4]

2.2. Pumping station

Pumping station is a construction with accompanying electromechanical equipment by means of which water is pumped from the channel area of a lower level to a higher level [5]. In this paper sewage shaft pumping stations were selected. Such pumping stations are used in drainage when it is necessary to remove waste water from communities, when they need to be purified and drained into the receiver, as shown in Figure 2. There are many such cases in practice that increase both in the sewage network itself and at devices for waste water purification and sludge processing.

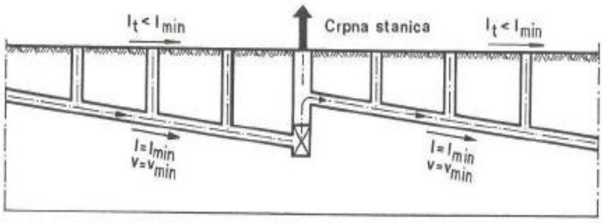

Figure 2. The position of the pumping station in the sewage system [5]

On the sewage network, pumping stations are necessary for lifting waste water from deeper into shallower channel parts when the channel inclination is greater than the surface inclination. Therefore, insisting on complete gravitation drainage would require channel depths much greater than the ones which are economical – 6-7 meters. Basic parts of such pumping stations are pumping container, machinery compartment and control room.

Pumping container is a room that is used for collecting and retaining the water pumped from it. Its size heavily depends on the work mode of pumps and inflow, so it is specially dimensioned. In larger pumping stations several mutually separated pumping containers are constructed, in order to allow for revision and repairs without stopping the operation of the pumps. Water enters the pumping container through one or more openings (inlets) directly or through grids and meshes. It is necessary to place gate valves on openings in order for the pumping container to be emptied from time to time. In pumping stations with immersed pumps the pumping container space should be adapted to the pump size as well. In the case of dry-construction pumps, within the pumping container the beginning of the pumping pipe equipped with suction baskets is placed. Pumping container must have a communication opening and communication elements, ventilation opening and overflow that activates at the filling level that exceeds the allowed one. Furthermore, the bottom of the pumping container is constructed as a slope down to the lowest point, where a sludge outlet is constructed for the purpose of emptying the container.

Machinery compartment is used for positioning pumping aggregates, control instruments, suction pipe endings and beginnings of discharge pipelines with accompanying water supply armatures, in order to connect pumping aggregates into a unique pressure system and other equipment. The machinery compartment must be constructed with suitable openings for communication, maintenance, equipment assembly and disassembly. If the equipment is heavy, a crane is set up as well. Within this space ventilation should be ensured too, as well as heating, if necessary. In smaller pumping stations with immersed pumps there is no machinery compartment.

Control room is a space that contains required electronic equipment for automated control of pumping aggregates, i.e. pumping station control. The automation consists of turning the pumps on and off according to their work mode. Along with this, the automation system ensures constant workload of all pumps, including the back-up ones. Within a pumping station an energetic connection should be ensured, according to the requirements made by the electricity distribution company. Thus, a transformer station is often constructed next to a pumping station, especially for pumping stations of a high installed capacity.

3. PROTOTYPE MODEL OF A PUMPING STATION

This chapter describes digital control system parts required for enabling the operation of a pumping station according to technological requirements of the process. It is necessary to establish communication with the measuring and active equipment at the station, create a control program and develop an interface for the operator.

3.1. Modeling a pumping station

A detailed prototype model of a pumping station contains all necessary technical parts that allow for the simulation of the pumping station operation. Water level movements are simulated manually using panels. Devices for measuring the water level in real pumping stations are substituted by three end switches on the prototype model. As the water level simulation panel moves from one end point to its other end point, it turns the end switches on or off. Each end switch represents a single water level: low level, medium level, high level. By turning them on or off signals on their activity are passed through to PLC inputs. The model contains two DC motors that replace the actual pumps. The control is carried out by a Siemens Simatic S7-1200 CPU 1214C PLC, and a communication GSM/GPRS modem towards a desktop computer with a visualization application carried out on the TIA-Portal Runtime program platform. The construction of the prototype model of a pumping station is shown in Figure 3.

Figure 3. Pumping station prototype model

3.2. Connecting the equipment

Sensors and actuators are connected to the PLC by means of the input-output unit. Signals generated by sensors, i.e. signals that can be accepted by actuators, may be digital or analog. Digital sensors are present in processes where the on-off control is used. Analog signals are used in measuring levels and in places where the on-off information of a device is not sufficient. Voltage levels of digital signals range between 0 V and 5 V for the logic 0, i.e. between 14 V and 30 V for the logic 1. Voltage and current analog signals range according to standards: 0–20 mA and 4–20 mA, i.e. 0–10 V and -10–10 V.

Electric circuits of digital inputs and outputs on individual input and output modules may be electrically insulated from all other inputs and outputs, as well as from the processor (CPU). Such galvanic separation is carried out by allowing for a separate power supply for each module and the accompanying sensors, i.e. actuators. The insulation towards the processor is achieved by additional optical coupling, whereby the transfer is made from external voltage levels 24 VDC or 110/220 VAC to internal voltage levels 5 VDC.

3.3. Control program

The condition for connecting the first pump is that the water level passes the low and medium level. If the water level continues to grow and passes the high level, the other pump is switched on too. Both pumps are switched off when the water level drops below the low level.

Pumps are divided into working and auxiliary ones. At the beginning of each new work cycle of the pumping station, i.e. with every drop of the water level below the low level, the pump role changes. The pump which was the main one in the previous cycle becomes auxiliary, and the pump which was auxiliary becomes the main pump.

3.4. Communication interface and visualization

Communication interface has several purposes. The main purpose is communication with the computer for the purpose of defining the program being executed, which should be entered into the PLC memory. Furthermore, an important application of the communication interface is the possibility of communicating with other PLC devices, creating a distributed control system network [6]. Along with this, communication with the central control system is allowed – SCADA.

System visualization (SCADA) of a pumping station is made in the way that all relevant pumping station parts are visible on it. Furthermore, it signalizes all significant changes during the pumping station operation. The presentation and arrangement of objects on the interface must allow for a quick, simple and easy to understand insight into the state of the system being shown.

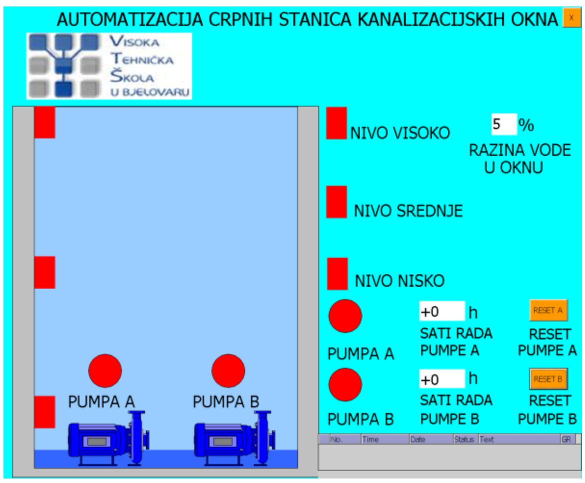

Figure 4. System visualization

Figure 4 presents the appearance of the pumping station in the sleep mode. The figure shows two pumps, pump A and pump B, water level in delimiters (so called *pears*), cumulative sum of working hours of individual pumps, which can be reversed at any moment, and the percentage of water in the shaft. For the case shown it was arbitrarily defined that the water level in the shaft amounted to 5 % (so called *residue*).

The contemporary technology of developing PLC devices and communications allows for communication interfaces for connecting PLCs to simpler communication protocols. The most frequent communication protocols in automated systems are Modbus, ASCII, Remote Link, Profibus and Ethernet. Communications between PLCs and mobile devices and web server are also possible. An example of such networked distributed system with advanced communication characteristics is shown in Figure 5.

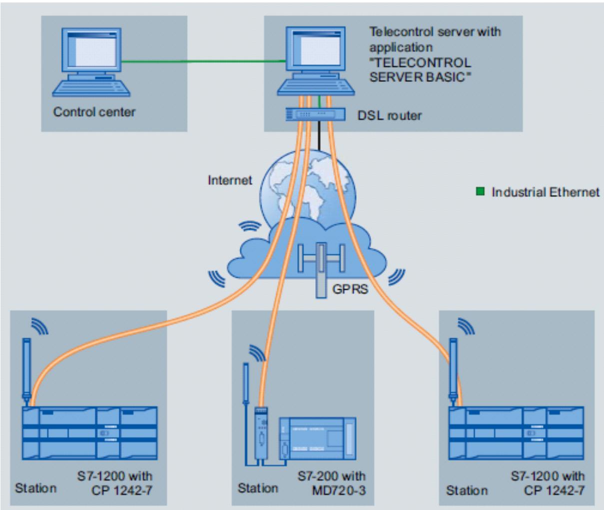

Figure 5. GSM/GPRS network of several PLCs and a control center [6]

4. RESPONSES OF THE PUMPING STATION MODEL DURING OPERATION

A graphical representation of the basic work cycle of a pumping station is shown in Figure 6. The black line marks the water level determined at the level of 5 % when the pumping station does not operate. As the water level rises, the level amounting to 15 % is recognized, which is shown in the visualization right away. After the continual increase of water level, the next discrete level amounting to 55 % of the total shaft height is recognized. At that moment the main pump is switched on (pump A in this iteration), which is marked with the red line. It operates until the water level drops again below 15 %. After the finished cycle the main and the auxiliary pumps switch their functions. In the next cycle, which is identical as the previous one, after the water reaches the level of 55 %, the main pump of this cycle is switched on, pump B, which is represented in the blue line. Pump B operates until the water level drops below 15 % within the shaft.

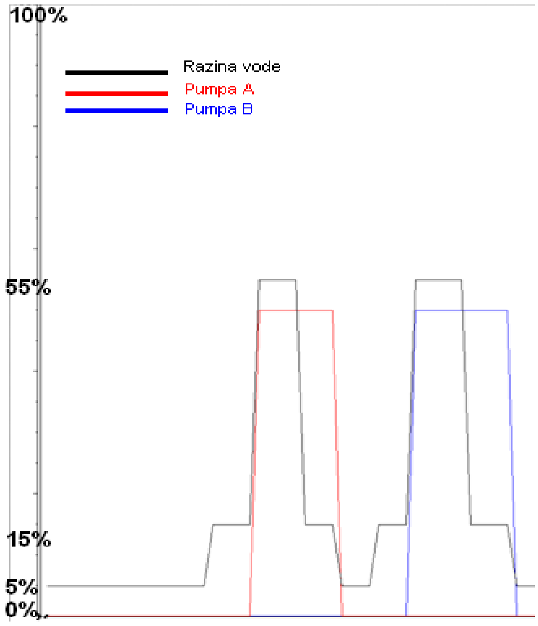

Figure 6. Graphical representation of the main cycle operation

Figure 7 shows two alarm work cycles of a pumping station when both pumps are turned on. The water level marked with the black line increases from 5 % to 15 % of the shaft height, and then to 55 %. At that moment the main pump is switched on, whose operation is marked with the red line. After the water level continues to rise, a discrete level amounting to 95 % is reached and the auxiliary pump represented in the blue line is switched on. Pumps switch off after the water level drops below 15 %. In the next alarm cycle pump functions are exchanged.

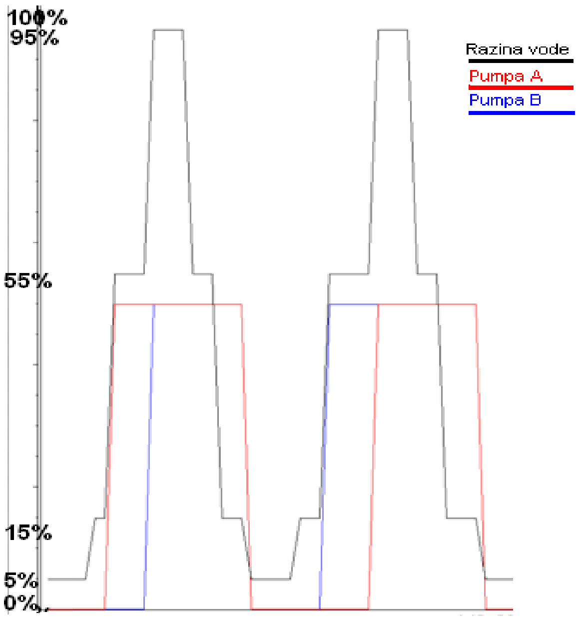

Figure 7. Graphical representation of the operation of two cycles, high level

5. CONCLUSION

Automated pumping stations are used for increasing the efficiency and reliability in the operation and remote control. At an automated pumping station it is easier to carry out maintenance, the safety is increased and there is the possibility of quality monitoring during the operation. Should the need arise that work modes of individual pumps are altered during the operation of a pumping station, it is easier to carry out the changes if the pumping station is automated. This paper represents an example of automation implementation in everyday working environment. For instance, the contemporary car industry is unimaginable without automated plants and processes.

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