Models of Objects of Control in the System for Monitoring and Dispatching on Metropolitan-Sofia

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Abstract – **The purpose of this paper is establishment of models of SCADA – system DISIM that is incorporated into the Central Dispatching Post of Sofia Metropolitan. Its functions are related to a remote visualization and management of devices in Trains operation (DISIM-V) and Power transmission system (DISIM-E). These models are used as a basis for realization of a simulator of both SCADA systems.**

Keywords – **Dispatching systems, metropolitan, modelling.**

I. INTRODUCTION

Dispatching system DISIM is implemented in Metropolitan Sofia. It is a complex structure of technical, software and organizational resources related to certain rules, providing control and operating on the train traffic process and power supply of the electrical equipment. Its purpose is to monitor and directly automatically control the processes and foremost to ensure the safety of passengers. In general, the control is performed automatically, while operating is done either automatically or through operator commands submitted by the dispatchers of the Central Dispatching Post (CDP). Therefore this is a contemporary Supervisory Control and Data Acquisition system (SCADA). It consists of several independent systems, the most important of which are DISIM-V for dispatching and control on the train traffic and DISIM-E for monitoring and control on the traction substations and electrical equipment [1], [6], [7]. The purpose of each SCADA-system is centralized data acquisition of remote geographical sites, information processing and visualization and generation of managerial impacts. The correct and reliable functioning of SCADA system is crucial for the functioning of the whole system [1], [2]. The point of the management is that these complicated technical systems implement an objective function when the external conditions are changed within fixed limits: their behavior is set up depending on the assessment of the external situation under a definite criterion in compliance with the fixed purpose. Therefore, the management is a process of forming the most effective behavior of the system aiming at implementation of appointed functions. The means for realization of management are the control units (where decision making is accomplished) and the actuators (which convert the information about the adopted decisions into actions directed towards achievement of management purposes). The following processes could be added to the more important and basic technological ones, subject to management in the metropolitan:

- Operation of underground trains;
- Uninterruptible power supply of the rolling stock and many other consumers of electric power (for their own needs);
- Different engineering sanitary and technical structures (escalators, pumps, fans, heating and lighting);
- ensuring possibility for local management of trains in the region of each station;
- giving information to passengers for the remaining time until the arrival of the following train and etc.

The great complexity of these processes is determined by the fact that each one is distributed in all stations on the territory of the underground and the management has to cover all these parts. In this sense the metropolitan represents a typical non-concentrated object. It is known that many special requirements for automatic control of such objects independently of the manufacturing industry are presented [3]. The complexity of the processes in metropolitan is growing because of the management needs to ensure safe transport, according to strict European standards.

The aim of this paper is establishment of structural models and mathematical description of processes in object levels of SCADA-systems DISIM-V and DISIM-E. The suggested models could be used as a basis for elaboration of a simulator of both SCADA-systems.

II. STRUCTURAL MODEL OF A SYSTEM FOR MONITORING AND CONTROL ON METROPOLITAN-SOFIA

Each SCADA-system consists of three formal levels [1], [6], [7]: Upper (Dispatching) level, Communication level, Lower (Object) level. The overall structural model of the object level of the system DISIM-V for monitoring and dispatching on train traffic is shown in Fig. 1. Trains operation in the metropolitan is marked as an object of control which includes: all the trains situated along the route at a fixed moment, the elements of the railway track, the signaling devices. The right interaction between the trains and the elements of the railway track has to ensure running of the technical process under the given algorithm, in this case – the actual timetable of trains operation for a fixed period. Normally, different disturbing impacts (damages of the rolling stock or the railway track, incorrect actions of the operational staff and etc.) could influence the process passing. In most cases the disturbing actions represent a reason for disco-ordination of the system exit. Each disco-ordination, i.e. divergence from the timetable, has to be considered a warning for generation of a suitable management decision.

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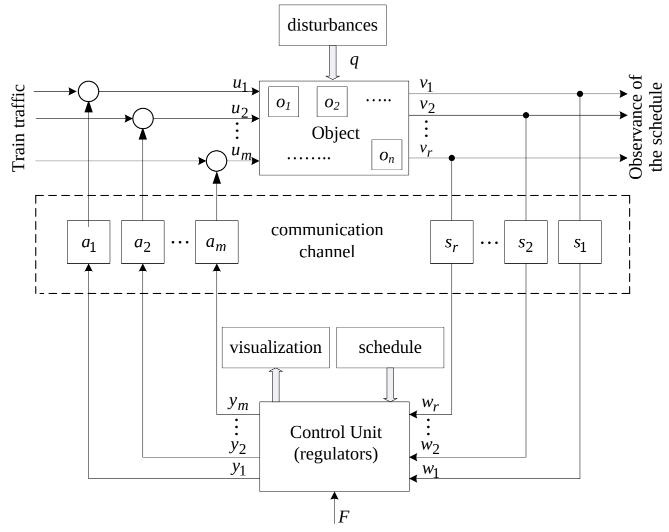

Fig. 1. Structural model of the object level of a system for dispatching and control on train traffic

All the trains operating along the section represent the system entrance. The system exit is the real implementation of the traffic timetable and the data reflecting the status of the different railway track elements. The information about the moment location of the trains is received from sensors s_i ($i=1\ldots p$, where p is the number of the track circuits, mounted along the section). The rest part of sensors s_j ($j=p+1,\ldots, r$) are situated in the signaling devices, points and other elements of the railway track. Actuators $a_1\ldots a_m$ are used for the realization of switching of traffic lights, points, etc.

The overall structural model of the object level of the system DISIM-E for monitoring and control on traction substations and electrical equipment is shown in Fig. 2. In this case, the object of control includes all main physical objects liable to control and management by the system: complex switchgear 10kV (disconnector and three-positional switchgear); traction transformer 10kV/825V; traction rectifiers; switchgear 825V; disconnector 825V; transformer 10kV/0,4kV; disconnector 0,4kV; charger devices and accumulator batteries. Most of the sensors and actuators are embedded in multifunction protection relays mounted at switchgears, transformers and other devices.

Data for normal state of these objects are embedded in the control unit memory. In contrast to DISIM-V system a fixed number of programmes, corresponding to the system reaction in case of arising of certain events, needs to be included in the managing device. These programmes establish an algorithm of switching over the object after assessment of the particular situation.

Visualization of the object status is envisaged in both models. It ensures monitoring by the dispatchers in the CDP and by the traffic manager on duty in the respective underground station.

In both models the object of control consists of $\boldsymbol{n}$ subsystems ($o_1\ldots o_n$). It has $\boldsymbol{m}$ inputs of entering input effects $[u_1(t),\ldots,u_m(t)]\in U$ and $\boldsymbol{r}$ outputs, which are obtained respectively the output signals of the system $[v_1(t),\ldots,v_r(t)]\in V$.

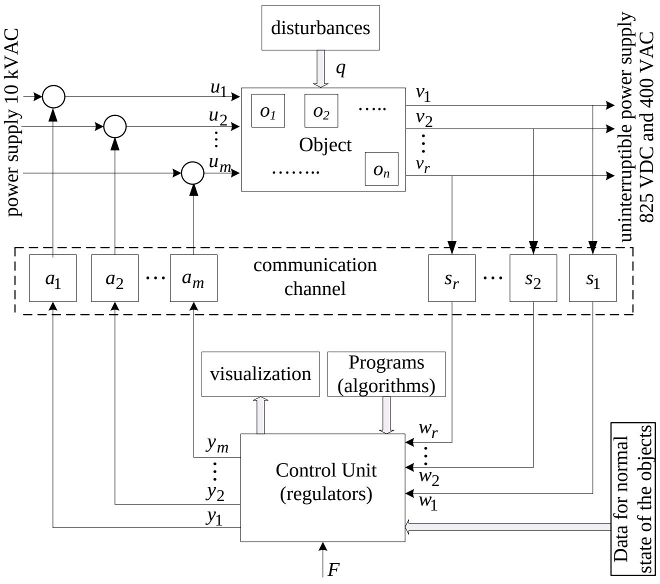

Fig. 2. Structural model of the object level of a system for monitoring and control on traction substations and electrical equipment

These signals are fed to the control unit by $\boldsymbol{r}$ number of sensors ($s_1\ldots s_r$) [3].

The control unit has a corresponding number of $\boldsymbol{r}$ inputs ($w_1\ldots w_r$) and $\boldsymbol{m}$ outputs ($y_1\ldots y_m$). The control system affects on the object by $\boldsymbol{m}$ actuators ($a_1\ldots a_m$).

The technical state $\boldsymbol{X}$ of the object of control is defined on the base of information received from the sensors and after computing operations. It can be interpreted as a technical grade of state $\boldsymbol{G}$, which corresponds to a response of the control system.

Each state x_i of i -th subsystem, $i\in[1,n]$, expresses its current state. Thus $[x_1(t),\ldots,x_n(t)]\in X$ expresses the current state of the object of control.

The transition of a subsystem from one state $x_i(t_1)$ to another $x_i(t_2)$ at $t_2>t_1$ determines its dynamics. It may be a result from the action of external control signals or due to internal disturbances.

If at initial time t_o the subsystem is in a state $x_i(t_0)\in X_0$ and there are no disturbances, then the change of its state is described by the equation:

$$x_i(t)=F[t,t_0,x_i(t_0)], \tag{1}$$

where F is objective function.

If the change in the state of the system is due to the action of an external signal, changes in the state is described by the equation

$$\dot{x}_i(t)=F[t,t_0,x_i(t_0),u(t)], \tag{2}$$

wherein the output signal is formed on:

$$v(t)=F[t,x_i(t),u(t)], \tag{3}$$

The dynamic model $\boldsymbol{G_p}$ of the object of control of the structures shown in Figs. 1 and 2 may be expressed in the form:

$$\begin{aligned}\dot{x}(t) &= A_p.x(t) + B_p.u(t)\\ v(t) &= C_p.x(t)\end{aligned}, \tag{4}$$

where *x(t), u(t), v(t)* and matrices with constant coefficients A_p, B_p и C_p are the relevant dimension.

Control unit is a specialized computing system and operates in discrete time with sampling period *T*. Programmable logic controllers (PLC) are widely used as control units in contemporary systems for monitoring and control on complex technical objects [1], [2], [7]. They offer high level of performance in the execution of the control program set in microprocessor. They are also equipped with a large number of digital and analog inputs and outputs, which can be increased by including additional expansion modules. PLC can be connected to a network and work as master or slave devices, and offer the ability to transmit data at high speed.

The technical state ***Z(κ)*** of the control unit at the sample time ***κT*** can be expressed as a function of the technical state ***Z(κ-1)*** in the preview sample time and information received on its inputs. Thus the dynamic model $\boldsymbol{G_c}$ of the control unit in the sample time *kT* can be expressed by the following equation

$$\begin{aligned}z(k) &= D.z(k-1) + E.w(k)\\ y(k) &= G.z(k) + H.w(k)\end{aligned}, \tag{5}$$

where *z(k) = z(kT), w(k) = w(kT), y(k) = y(kT)* and matrices *D, E, G* and *H* are the relevant dimension. Each of these matrices consists of not only constant coefficients, but of regulators, associated to the appropriate input signal as well. Programmed PID (Proportional-Integral-Derivative) regulator allows the process control to accurately maintain setpoint by adjusting the control outputs. PID can be used to obtaining a fast response of a disturbance appearance. In steady state operation, it regulates the value of the output so as to drive the error $\boldsymbol{e_i}$ to zero. A measure of the error is given by the difference between the setpoint (the desired operating point of the appropriate sub-object of control) and the process variable (the actual operating point calculated on the base on the received information).

The principle of PID control is based upon the following equation that expresses the output, y_i, as a function of a proportional term, an integral term, and a differential term:

$$y_i(t) = K_i.e_i + K_i.\int_0^t e_i.dt + y_{i0} + K_i.\frac{\partial e_i}{\partial t}, \tag{6}$$

where:

$y_i(t)$ is the i^{-th} output as a function of time ($i = 1 \ldots m$);

K_i is the loop gain of the appropriate regulator;

e_i is the loop error (the difference between setpoint and process variable);

y_{i0} is the initial value of the i^{-th} output.

In order to implement this control function in a digital description, the continuous function must be quantized into periodic samples of the error value with subsequent calculation of the output. The corresponding equation, which is the basis for the solution of the digital algorithm, is:

$$\begin{aligned}y_i(k) = K_i * e_i(k) + K_{iI} * \sum_{j=1}^{k} e_i(j) + y_{i0} + \\ + K_{iD} * [e_i(k) - e_i(k-1)]\end{aligned}, \tag{7}$$

where: $y_i(k)$ is the calculated value of the i^{-th} output at sample time *k*; $e_i(k)$ is the value of the loop error of the appropriate regulator at sample time *k*; $e_i(k-1)$ is the previous value of the loop error (at sample time *k-1*); $e_i(j)$ is the value of the loop error at sample time *j*; K_{iI} is the proportional constant of the integral term of the i^{-th} output signal:

$$K_{iI} = K_i * \frac{T}{T_{iI}}, \tag{8}$$

T is the sample time (this is the cycle time at which the processor recalculates the output values); T_{iI} is the integration period of the i^{-th} output (also called the integral time or reset); K_{iD} is the proportional constant of the differential term of the i^{-th} output signal:

$$K_{iD} = K_i * \frac{T_{iD}}{T}, \tag{9}$$

T_{iD} is the differentiation period of the i^{-th} output (also called the derivative time or rate). The differential term is proportional to the change in the error.

As a result of the repetitive nature of the digital algorithm solution, a simplification in the Eq. (7), which must be solved at any sample time, can be made. The simplified equation is:

$$\begin{aligned}y_i(k) = (K_i + K_{iI} + K_{iD}) * e_i(k) + \\ + Y_i(k-1) - K_{iD} * e_i(k-1)]\end{aligned}, \tag{10}$$

where $Y_i(k-1)$ is the value of the integral term at sample time *k-1* (also called the integral sum or the bias):

$$Y_i(k-1) = K_{iI} * \sum_{j=1}^{k-1} e_j + y_{i0}\ . \tag{11}$$

The bias is the running sum of all previous values of the integral term. Several constants are also part of the integral term, the gain (K_i), the sample time (*T*), and the integral time or reset (T_{iI}), which is a time used to control the influence of the integral term in the output calculation.

In many control systems, it might be necessary to employ only one or two methods of loop control. Setting the value of the constant parameters makes the selection of the type of loop control desired. If the derivative action is not required and PI regulator may be used, then a value of 0.0 should be specified for the derivative time T_{iD}. If the integral action is also not required, then a value of infinity “INF” should be specified for the integral time T_{iI}. Even with no integral action, the value of the integral term might not be zero, due to the initial value of the integral sum y_{i0}. Then the proportioning control continuously adjusts the output dependent on the relative values of the process variable and the setpoint. Many control designs incorporate offset as a digital programmable value that allows redefining the output requirement at the setpoint. A proportioning control without offset will settle out somewhere within the proportioning band but likely not on the setpoint. The offset may be used in conjunction with Integral time (reset) that allows for quicker settling at setpoint. Reset redefines the output requirements at the setpoint until the process variable and the setpoint are equal. PID functions allow for the precise control of difficult processes (for example control on the voltage, current, temperature, positioning of the actuators, etc.). Rate (Derivative time) is activated at a slope change of the error. Its effect applies the “brakes” in an attempt to prevent overshoot (or undershoot) on process upsets or startup. The process variable can be controlled without oscillations around the setpoint.

Most of the objects of control in SCADA-system DISIM are slowly acting – their reactions have low repeatable frequency. In this case there is no need to use more complicated regulators than P regulators.

The communication level for both systems is constructed in compliance with the principle of the Optical Open Transport Network (OTN). This is a digital communication network built up by nodes which are interconnected by a double optical fiber ring [6], [7], [8]. Because of the double ring structure, OTN guarantees an unparalleled degree of reliability. Should one fiber ring or node fails because of any reason (fire, rupture etc.), then the other ring and nodes take over immediately, thus keeping the whole network operational round the clock. The system will always find a way around any problem without affecting its users. The OTN nodes also offer redundancy of the main components such as power supplies, common logic cards and optical modules.

OTN allocates a dedicated amount of bandwidth to each application. Each application has its own 'lane' or layer in the fiber tunnel, with guaranteed bandwidth. This allows the all applications run smoothly on the OTN, without interfering with each other.

An OTN network is often applicable for extended transport environments such as tunnels, railways, subways, etc. All existing applications are linked by fully transparent manner. This network is “Open” because it transfers all available communication applications, provides Accident Prevention and limiting applications, includes Interface cards for voice, data, digital video and Ethernet [4], [8].

Dispatcher level realizes the logic functions in accordance with the requirements of the technology for the train traffic, passenger’s safety and monitoring and control on the electrical equipment. This process includes also functions of displaying the information and human-system dialogue (displaying track development, signals status, location and movement of trains at any time, status of all electrical equipment in the substation, etc.), as well as working-out and starting-up commands.

This level consist of functional modules representing these functions and appropriate one or more windows by which Dispatcher communicates with the system. Functions of this level are fully described in [1], [5], [9], [10].

III. CONCLUSION

The structural and functional models developed in this paper are the basis of elaboration of an imitation model of the system for monitoring and management of processes in the underground. Such model has been synthesized and a simulator of Dispatching SCADA systems DISIM-V and DISIM-E has been structured at Todor Kableshkov University of Transport. The imitation models of object levels of both systems have been installed on a server using special software. The dispatcher level has been installed on five computers that use the server for the communications with the objects. Opportunities for simulation of different real working regimes for both systems have been created. The trainers would be capable of coming in depth in the essence of the contemporary SCADA technologies adopted to be the main and increasingly perspective method for automatic management of complicated dynamic processes in crucial and critical fields in terms of safety and reliability.

A comprehensive survey of the contemporary, modern and effective SCADA-system DISIM is not possible due to the special working regime and admission in the CDP, local station posts (the work places of the traffic managers on duty) and substations. Thus, the availability of such a system model is extremely useful for personnel training and increasing the qualification of operational specialists in the metropolitan, electricity distribution companies and the railway infrastructure.

Many examinations on this simulator have been carried out and its proper work has been verified [5], [9], [10]. Thus an experimental verification of the developed models is done.

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