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Research of the Data Exchange Processes during the Automated Control of Autonomous Electric Power Systems

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Abstract: *The article proposes a technique for studying the information exchange processes between the elements of the automated control system of the autonomous electric power system (AEPS). The analysis of information flows in the network of the distributed control system AEPS, which are formed by the software components of the automated workplace of the operator, and transmitted to the hardware automation means has been performed. The use of queuing theory allows to estimate the possibility of real-time system operation. The obtained analytical expressions, which allow the calculation of the average queuing time of the queuing system, are used to select the scan period in the SCADA system, which does not result in the loss of data packets. An analytical relation autonomous between the complexities of the AEPS scheme, which is used as part of the operator's automated workplace for the automated control of the AEPS, and the workload of the communication channel has been established. It has been proposed to use an integrated complexity indicator of circuit for comparison of the AEPS schemes in terms of the load on the information channel.*

Keywords: *SCADA, information flows, request queue, scan period, autonomous electric power system, software.*

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I. Introduction

Software for automated control of self-contained power system (SCPS) is an integral part of automated control system (ACS) which is essentially a hardware-software complex. SCPS ACS is classified as a real-time control system, which stipulates the importance of calculation of its temporal performance. SCPS ACS is space-distributed, therefore, the time delays related to data transfer in the network, may be deemed as a result of the effect of three main factors: data transfer rate limit, communication line load and the distances between the operator's automated working station and the automation equipment. SCPS hardware-software equipment will not operate adequately is they are not provided with the reliable information about parameters of power units and other system elements. Imperfect control of information channels, without regard of time delays that occur during the processing of the queues of requests and date transfer in the network results in degradation of SCPS ACS operation. To avoid the negative effect of such delay, the automation systems and software should be designed in consideration of this factor.

Problem setting

To provide efficient SCPS automated control, it is necessary to determine the value of the minimal period of SCADA-system scanning at which no data packages are lost. To solve this operational problem, the authors suggest a method for calculation of parameters of queuing system that processes the requests from the automated control software components and controls SCPS parameters, which constitutes the SCADA-system.

II. Literature Review

To implement all the necessary functions of power system remote control through a software it is necessary to have the necessary facilities for creation of a power plant diagrams, real-time monitoring and control of self-contained power system, analysis of power units and software operation modes [1]. At this, as is mentioned in the paper [2], it is important to adhere to the formal approach to description of software components and automation application software components. According to the principle of construction of hierarchical control system, the stage of uncertainty of information about the system condition rises with the hierarchy level elevation, and, correspondingly, the period of control action generation increases [3], [4]. Besides, the data communication of SCADA-system with the middle-level automation facility is a logical structure of the network of "one to many relationships", which is implemented in the common bus topology, therefore, the greatest contribution to the time delay length is made by the data transfer rate, the distance between the devices and SCADA-system and the data channel load.

The papers [5], [6] state that the most significant (one or two orders higher than that of the others) impact on the delays is made by the data channel loading which occurs due to the processing of the queues of requests from ACS software. The papers [7], [8] suggest the approach to determination of time parameters of SCPS ACS information processing network using the pattern networks. However, a disadvantage of the suggested approach is the fact that the result of the calculations is the mean value of duration of processing of request queues with similar priority by queueing systems. It does not provide any answers to the question of which exactly scanning period should be chosen for provision of efficient SCPS automated control. To that end, it is possible to use the queueing theory which has been implemented in various domains for study of queuing, as is shown in the papers [9] – [11], however, the calculation of parameters of queueing systems for self-contained power system distributed control system has its specificity which is considered in this work.

Basis material

General queuing is performed cyclically. The time between two consecutive data exchanges is called "scanning period". For efficient utilization of communication channel and the predictable response time, the scanning period should equal or exceed the time of serving all the request of the general queue:

$$t_{sc} \geq \sum_{i=0}^{M} L_i \cdot t_{pr\,i} , \qquad (1)$$

where t_{sc} is the scanning period; M is the number of types of the components used in the diagram; L_i is the length of the queue of requests of $i-$type components; $t_{pr\,i}$ is the time of processing of $i-$type component request.

The general queue is made of constant and variable elements. The length of the queue of requests of the components that comply with theconstant queue elements is invariable and equals to the number of the parameters measured:

$$L_i = N_i , \qquad (2)$$

where N_i is the number of parameters measured.

The lengths of variable queues of components requests depends on the number of the measured parameters of the components, the intensity of input streams of requests and the scanning period:

$$L_i = N_i \cdot \lambda_i \cdot t_{sc} , \qquad (3)$$

where λ_i is the intensity of input streams of $i-$type requests.

For "Generator" components the average number of variable measured parameters (voltage and/or current instantaneous values) may be calculated as the arithmetic mean:

$$N_G = \frac{2 \cdot M_{G2} + M_{G1}}{M_{G0} + M_{G1} + M_{G2}} , \qquad (4)$$

where M_{G0}, M_{G1}, M_{G2} are the numbers of "Generator" components, for which the current or voltage are not measured; one parameter is measured and the both parameters are measured correspondingly.

For "Diesel" components, the average number of measured parameters is calculated similarly:

$$N_D = \frac{\sum_{i=1}^{M_D} N_i}{M_D} , \qquad (5)$$

where M_D is the number of "Diesel" components in the diagram; N_i is the number of measured parameters of $i-$th "Diesel" component.

The time of request processing $t_{pr\,i}$ depends on the data exchange parameter (rate, stop bit number) settings and the size of request and response packages.

Table 1 presents the package size in bytes for each of the components that may participate in the data exchange.

To compare the complexity of the diagrams in terms of the data exchange channel load and to facilitate the calculations for each parameter (operation), a weight coefficient - the ratio of the total number of bytes of the request and the response to the base number (selected as the smallest valuein the table - 15 bytes) is introduced. Then the request processing time is defined as follows:

$$t_{pr\,i} = 1.2 \cdot k_i \cdot t_{tr}, \quad (6)$$

where k_i –

$$t_{sc\,avg} = \frac{1.2 \cdot t_{бtr} \cdot \sum_{i=1}^{N} M_i \cdot k_i}{1 - 1.2 \cdot t_{tr} \cdot \left(M_{aut} \cdot k_{aut} \cdot \lambda_{aut} + \frac{2 \cdot M_{G2} + M_{G1}}{M_{G0} + M_{G1} + M_{G2}} \cdot k_G \cdot \lambda_G + \frac{\sum_{i=1}^{M_D} N_i}{M_D} \cdot k_D \cdot \lambda_D \right)}, \quad (7)$$

Where $t_{tr} = 10/\upsilon$; N is the number of constant measured parameters ($1 \le N \le 5$); M_i is the number of parameters for which the $i-$th parameter is measured; k_i is the weight coefficient of the operation corresponding to the parameter (k_{aut} is the "Digital output control" for"Automation Device" component; k_G is "Obtaining of instantaneous voltage (current) values" for "Generator" component; k_D is the "Obtaining of diesel parameters values" for "Diesel"component); M_{aut} is the number of "Automation Device" component in the diagram; λ_{aut}, λ_G and λ_D are the intensities of input request streams related to the change of digital output conditions, obtaining of instantaneous generator voltage (current) values and obtaining of the diesel parameter values correspondingly; M_{G0}, M_{G1}, M_{G2} are the numbers of "Generator" and "Diesel Generator" components, for which the current or voltage are not measured; one parameter is measured and the both parameters are measured correspondingly; M_D is the number of "Diesel" components in the diagram; N_i is the number of the measured parameters of $i-$th "Diesel" component.

Table 1– Data package size

Operation	Component	Byte number			Coefficient
		Request	Response	General	
Digital output control	Control button, automation device	8	11	29	1.93
Obtaining of digital input status	Light emitting diode	8	7	15	1.00
Obtaining of root-mean-square voltage	Generator	8	7	15	1.00
Obtaining of root-mean-square current	Generator	8	7	15	1.00
Obtaining of frequency value	Generator	8	7	15	1.00
Obtaining of power coefficient value	Generator	8	7	15	1.00
Obtaining of instantaneous voltage values	Generator	8	115	123	8.20
Obtaining of instantaneous current values	Generator	8	115	123	8.20
Obtaining of diesel parameters values	Diesel (one parameter)	8	9	17	1.13

Using the mean scanning period, it is possible to obtain the mean length of the general queue:

$$L_{avg} = t_{sc\,avg} \cdot \frac{\upsilon}{10}. \quad (8)$$

The minimal scanning period at which data exchange without losses is possible, is calculated based on the mean value at boundary conditions – permanently open "Diesel Parameters" (for diesel with the maximal number of the measured parameters) and "Oscillograms" (for generator with the highest number of the measured instantaneous values) windows:

$$t_{sc} \ge \frac{1.2 \cdot t_{tr} \cdot \sum_{i=1}^{N} M_i \cdot k_i}{1 - 1.2 \cdot t_{tr} \cdot \left(k_{aut} + N_{G\max} \cdot k_G + N_{D\max} \cdot k_D \right)}, \quad (9)$$

where $N_{G\max}$ in the maximal number of the measured parameters (instantaneous voltage and/or current values) for "Generator" component; $N_{D\max}$ is the maximal number of the measured parameters for "Diesel" components.
Communication channel load may be calculated using the formula:

$$K_{load} = \frac{L_{avg}/t_{sc}}{\upsilon/10} \cdot 100\% = \frac{10 \cdot L_{avg}}{\upsilon \cdot t_{csc}} \cdot 100\%, \quad (10)$$

where t_{sc} is the selected scanning period.

Fig. 1 presents a SCPS diagram, for which the main parameters of data exchange system are calculated using the formulae (7) – (10).

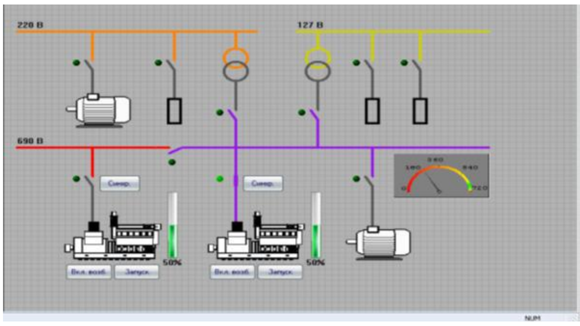

Figure 1 – SCPS diagram for calculation of the main parameters of data exchange system

Among the components for which the data exchange occurs, the diagram has:
–ten “Light Emitting Diode” components;
–ten “Automation Device” components with the input stream intensity of $\lambda_{aut} = 2.8 \cdot 10^{-3}\ \text{sec}^{-1}$ ($10\ \text{hours}^{-1}$);
–six “Control button” components with the input stream intensity of $\lambda_{aut} = 2.8 \cdot 10^{-3}\ \text{sec}^{-1}$.
–two generators within the “Diesel Generator” components. For the both, the root-mean-square voltage, current, frequency and power factor are measured (the instantaneous voltage and current values are measured only for the first generator). For the second one – only the instantaneous voltage values. The input stream intensity for the both generators is $\lambda_G = 0.1\,\text{sec}^{-1}$ ($360\ \text{hours}^{-1}$);
–two diesels within the “Diesel Generator” component. For the first one three parameters are measured, for the second one – four. The input stream intensity for the both diesels is $\lambda_D = 0.05\ \text{sec}^{-1}$ ($180\ \text{hours}^{-1}$).
The minimal scanning period value is determined from the formula:

$$t_{sc\,\min} = \frac{1.2 \cdot \dfrac{150}{9600} \cdot \left(10 \cdot k_{led} + 2 \cdot k_{D\,n} + 2 \cdot k_{D\,str} + 2 \cdot k_{freq} + 2 \cdot k_{coef}\right)}{1 - \dfrac{150}{9600} \cdot t_{tr} \cdot \left(k_{aut} + 2 \cdot k_G + 4 \cdot k_D\right)},$$

and constitutes, after numeric value substitution, 0.590 sec. The mean scanning period $t_{sc\,avg} = 0.328$ sec. The mean data package length $L_{avg} = 312$ bit.
The dependence of communication channel load is determined by the ratio:

$$K_{load} = \frac{0.325}{t_{sc}} \cdot 100\,\%,$$

and is presented in Fig. 2 in graphic form.

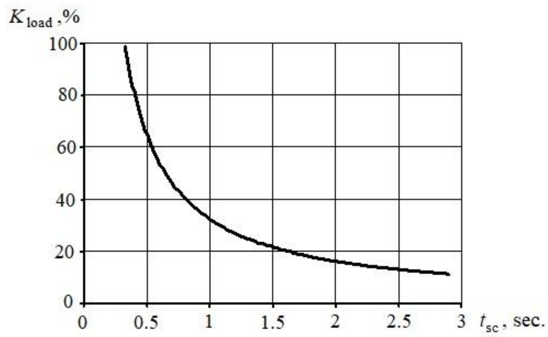

Figure 2 – Dependence of data exchange channel load on the scanning period

To compare the diagrams from the viewpoint of the information channel load, it is convenient to use the integral diagram complexity factor K_{dif}:

$$K_{dif} = \sum_{i=1}^{5} M_i \cdot k_i + k_{aut} + \frac{2 \cdot M_{G2} + M_{G1}}{M_{G0} + M_{G1} + M_{G2}} \cdot k_G + \frac{\sum_{i=1}^{M_D} N_i}{M_D} \cdot k_D \qquad (11)$$

where M_i are the numbers of the components for which the operations “Obtaining of digital input condition” are performed (“Light Emitting Diode” component, $i = 0$), “Obtaining of root-mean-square voltage” ($i = 1$), “Obtaining of root-mean-square current” ($i = 2$), “Obtaining of frequency value” ($i = 4$; operations with $i \in [2,4]$ are performed for “Generator” and “Diesel Generator” components); k_i are the operations weight coefficients (Table 1); k_{aut}, k_G, k_D are the weight coefficients of operations «Digital output control”, “Obtaining of instantaneous voltage (current) values”, “Obtaining of diesel parameters values” (Table 1) correspondingly.

III. Conclusions:

Based on the study performed the authors suggested a method of calculation of parameters that provide the determination of time of processing the queues of request from the SCPS automated control system components by the system, the assessment of communication channel load and prediction of time delays during the transfer of information –control packages through the network. Temporal performance of SCPS automated control provision depends upon its topology and the power system structure and the intensity of the streams of requests from the software components, therefore, the parameters of each SCPS ACS are calculated individually. To take into account the operations priority to prevent the loss of requests, the general queue is divided into for individual ones, which are processes consequently. The scanning period value depends on the length of these queues. The results obtained are the basis for selection of scanning system period at which no package data are lost.

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