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A Modernized Control System of the "Victoria" Pulse Modulator Complex

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Abstract—The results of designing an automated control system (ACS) of the Victoria pulse modulator complex, which is used for the high-voltage power supply of auxiliary plasma heating systems on the T-10 and T-15 tokamaks and gyrotron test benches, are considered. The ACS is based on digital and microprocessor devices and ensures control of the power circuit of high-voltage modulators, monitoring of the load parameters, and emergency protection of the power electrical equipment.

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STATEMENT OF THE PROBLEM

The Victoria pulse modulator complex (PMC) consists of 22 high-voltage modulators (80 kV, 3 MW) and is intended for the high-voltage power supply of auxiliary plasma heating units of the T-10 and T-15 Tokamak facilities and the gyrotron test bench of the National Research Centre Kurchatov Institute (Moscow). The Victoria PMC acts as a power source for auxiliary plasma heating systems, which include the ion-cyclotron heating, microwave heating, low-hybrid resonance heating, and an injection heating system.

The existing modulator control system was created in 1979 and does not meet the specifications of the presently designed information-controlling system of the modernized T-15 facility in relation to reliability of assemblies and arrangement of information channels of interaction of automation-equipped workstation operators and higher assemblies of the ACS of auxiliary heating systems and general-system ACS. The technical re-equipment project of the T-15 thermonuclear facility assumes replacement of the existing control system of the Victoria PMC, preserving and using at maximum the power part of the existing modulators for powering the equipment of the auxiliary plasma heating systems. The solution to this problem is considered in this paper.

DESCRIPTION OF THE HARDWARE-TECHNICAL SOLUTION

The principle of operation of the modulators is based on storing energy in an inductive storage, its conversion by a high-frequency inverter, subsequently transforming and rectifying the voltage. Figure 1 shows the simplified block diagram of the modulator.

The feature of the PMC operation consists in the need of forming control pulses, whose duration can vary in a wide time range from unities of milliseconds to several dozens of seconds. For example, the on-line control and modulator protection signals have a rise time of 1 μs; the response time to an event is no more than 10 μs, and some parameters (readiness, settings, etc.) with respect to the monitoring period and accuracy meet ordinary process requirements. Taking also into account that electric interfaces of all monitoring and control circuits are not unified, the use of commercial units for automation of the modulator is either impossible or requires application of specially designed auxiliary matching units, formers, and logic circuits, which are implemented at the hardware level.

The described hardware-technical solution to the stated problem is based on the application in the automated control system of some microprocessor units for automating the process equipment. In the subse-

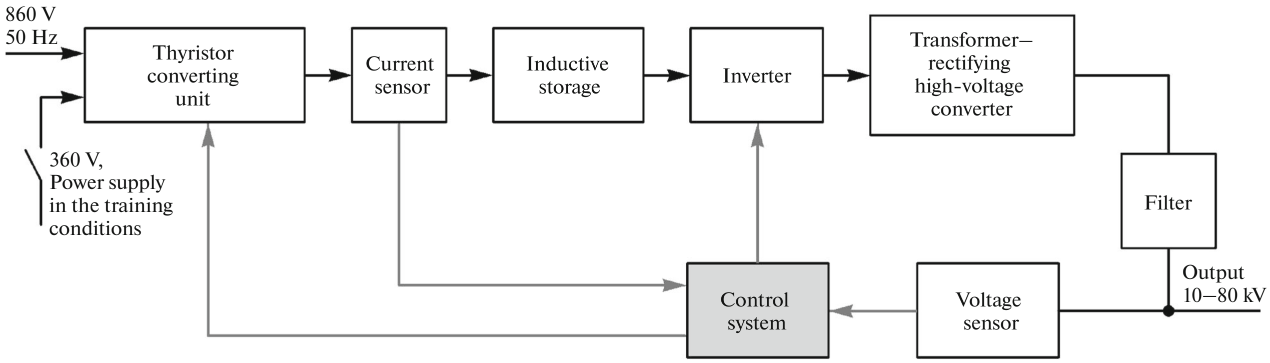

Fig. 1. Block diagram of the high-voltage modulator.

quent text, we consider in detail the implementation features of the system.

The ACS of the PMC ensures transmission of control signals from the ACS of auxiliary heating (AH) to high-voltage modulators, digital setting of parameters, and control of the Victoria PMC from automation-equipped workstation (AEWS) of the complex and control panels of the auxiliary heating systems. The ACS of the PMC is implemented as a two-level system (see Fig. 2).

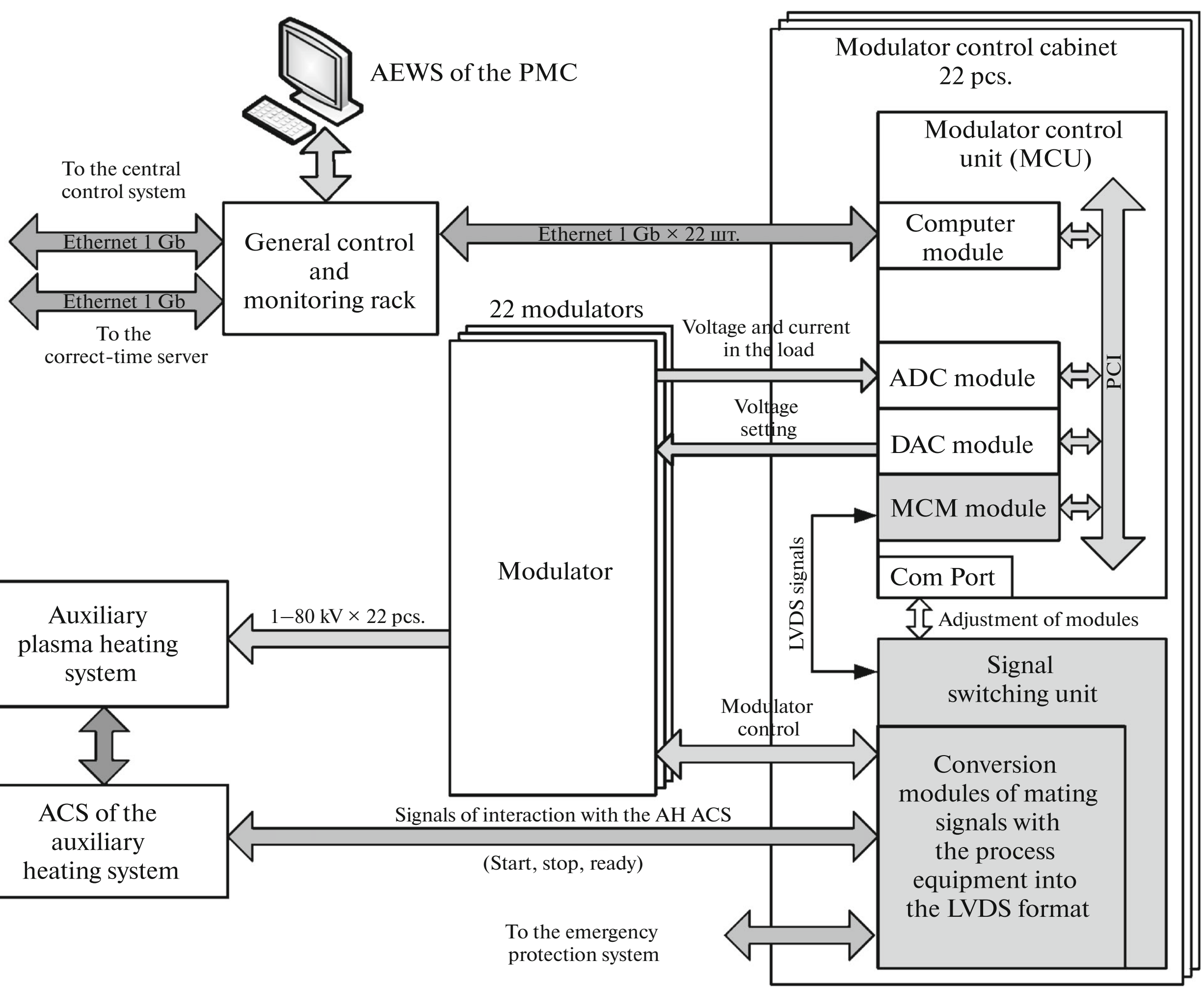

Fig. 2. Block diagram of the ACS of the Victoria PMC: (*ADC*) analog-to-digital converter and (*DAC*) digital-to-analog converter.

Table 1. Input and output discrete signals that are processed by the *MCM*

Names of signals	Designations of signals	Remark
	Input signals	
Ready/fault of the ACS of AH	*AHSRDY*	High level—Yes, low—No
Fault of the outer system	*ESYSEMR*	High level—Yes, low—No
Start/stop of the modulator	*START*	High level—start, low—stop
Fault of the modulator	*MDEMR*	Pulse (duration is 10 μs)
	Output signals	
Ready/fault of the modulator	*MDRDY*	High level—Yes, low—No
Approval	*MDACK*	High level—Yes, low—No
Beginning of the inductive-storage charging	*CHARGE*	Pulse (rise time is 1 μs, duration is 1 ms)
Leading edge of the working pulse	*RISEPULSE*	Pulse (rise time is 1 μs, duration is 1 ms)
Falling edge of the working pulse	*FALLPULSE*	Pulse (fall time is 1 μs, duration is 1 ms)
End of the working pulse	*DISCHARGE*	Pulse (fall time is 1 μs, duration is 1 ms)
Startup of the *ADC*	*ADCSTART*	High level—start, low—stop

The first level is represented by modulator control units (MCUs). Each MCU controls a separate high-voltage converter. The collection and primary processing of analog and discrete signals on the modulator-equipment state, transmission of digital control signals from the AH ACS to the modulators, and data transmission, which is supported by standard protocols, to the Victoria PMC control room, additional-heating ACS control room, and to the higher level of the automated system occur at this level.

The second level includes the general-control and centralized monitoring rack and operator's AEWS of the ACS of the Victoria PMC. The rack is intended for tracking the state of the control system as a whole, acquisition, recording, and primary processing of data from the modulator control units, and for the data transmission according to the standard protocols to the central control system.

The AEWS enables an operator to monitor manufacturing processes of the PMC, ensuring signaling on emergency conditions and failures in the operation, and, allows one to form manual remote-control signals.

The modulator control unit is a commercial computer, equipped with input/output functional modules, and carries out:

—monitoring of operating parameters of the modulator, tracking of malfunctions and failures, including the operation of interlocks in cases of exceeded preset load current and voltage values, and emergency outage (in response to an external signal from the emergency protection system);

—acquisition, recording, and transmission of data on the monitored and controlled parameters during the PMC operation to the operator's AEWS;

—reception of control commands from the auxiliary-heating ACS, formation and transmission of signals to the modulator.

The basic element of the MCU is the modulator control module (*MCM*), intended for the input/output of digital or discrete signals via 32 wire lines with flexibly configured signal processing logic, which is based on the use of the programmable logic integrated circuit with the FPGA architecture (design of the TomICS-PROJECT, Tomsk).

During its operation, the *MCM* interacts with the auxiliary-heating ACS, modulator, and other units installed in the MCU. The logic interaction scheme of the *MCM* and other devices during the system operation is shown in Fig. 3.

The composition, purpose, and parameters of basic discrete signals that are processed and formed by the *MCM* are summarized in the table. The operation algorithm of the *MCM* module varies, depending on the selected operation mode. The following modes are admissible: generation of a single pulse; intrapulse modulation; emergency stop of the modulator; and the protection switching-off of the modulator in response to the signal from the AH ACS. The time chart of the *MCM* operation in one of the intrapulse modulation modes is shown in Fig. 4.

On conditions that the AH ASC ready signal *AHSRDY* has a high logic level, the high logic level is set on the signal *MDRDY* on the ready line of the modulator. Upon the receipt of the first jump to the high logic state of the signal on the line *START*, a control pulse is formed on the line *CHARGE*, and the *ADC* is also triggered.

Upon expiration of the time that is required for charging the inductive storage, a control pulse is formed on the line *RISEPULSE*. When the signal on

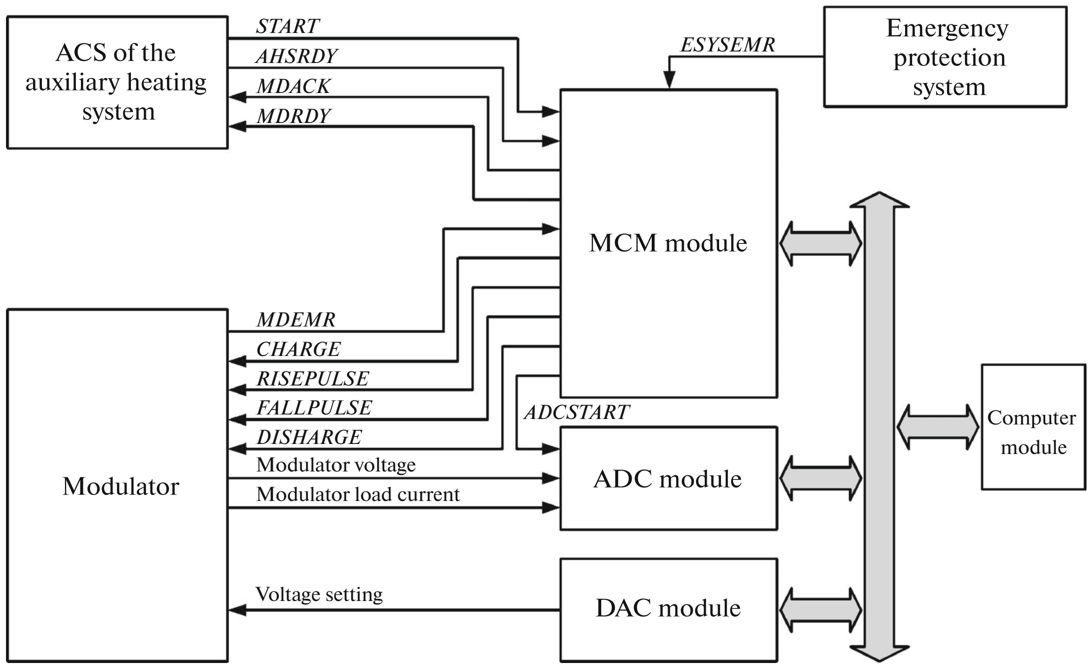

Fig. 3. Logic interaction scheme of the *MCM* and other devices.

the line *START* jumps to a low logic level, a control pulse is generated on the line *FALLPULSE*. With subsequent jumps of the signal *START* from the low logic to the high logic level, a control pulse is generated on the line *RISEPULSE*.

The modulator stops in the intrapulse modulation mode, when the signal on the line *AHSRDY* jumps from the high logic to the low logic state. In this case, a control pulse is generated on the line *DISCHARGE* and a trigger signal of the *ADC* (*ADCSTART*) is lifted.

In an emergency case, the *MCM* fulfills the protective-stop algorithm. In this case, a stop pulse of the modulator is formed on the line *DISCHARGE*, the high logic level is formed on the line *MDACK*, and the low logic level is formed on the lines *MDRDY* and *ADCSTART*.

A specific feature of the process equipment of the Victoria PMC and auxiliary heating systems consists in a large variety of discrete monitoring and control signals (0–24 V; 0–100 V; TTL; optical). For the conversion of different types and rated values of the mating signals of the process equipment into the necessary (for *MCM*) LVDS format of electric signals, modules of the signal switching unit (design of the TomICS-PROJECT, Tomsk) were used (Fig. 2).

All the modulator control devices are connected via a separate cable directly to the Ethernet switchboard, which is a part of the general-control rack. The physical channel of the data transmission from the MCU to the Victoria PMC control panel is optical, the data transmission interface is Ethernet, and the connection topology is radial. The MCU and the upper level of the system interact in accordance with the ModbusTCP protocol, which is accepted as the base protocol for the currently designed information-controlling system of the T-15 Tokamak (T-15 ICS). The external interactions of the MCU are executed by using the unitized command language, which represents facilities for description of the state diagram of units in the process of preparing the experiment and in the course of it [1].

The software of the general-control rack is intended for monitoring and storing information on the state of the ACS and the whole modulator complex. The collected information is kept in the database and accessible in response to inquiries of higher assemblies of the T-15 ICS. In the course of the experimental preparation, the software of the general-control rack interacts with the central control system for receiving data of the planned scenario of the experiment and fulfills the preoperational automated adjustment of the Victoria PMC equipment.

During monitoring and control of the power supply of the auxiliary plasma-heating systems, the AEWS of the Victoria PMC ensures displaying of information on the state of modulators in the AH ACS for the operator and the formation and delivery of control signals to the process equipment of the Victoria PMC (see Fig. 5). The application software of the AEWS of the Victoria PMC was designed in the Trace Mode 6.09 instrumental environment (AdAstra Research Group, Moscow).

The software of the AEWS of the PMC allows one to form equipment control commands: switching-on

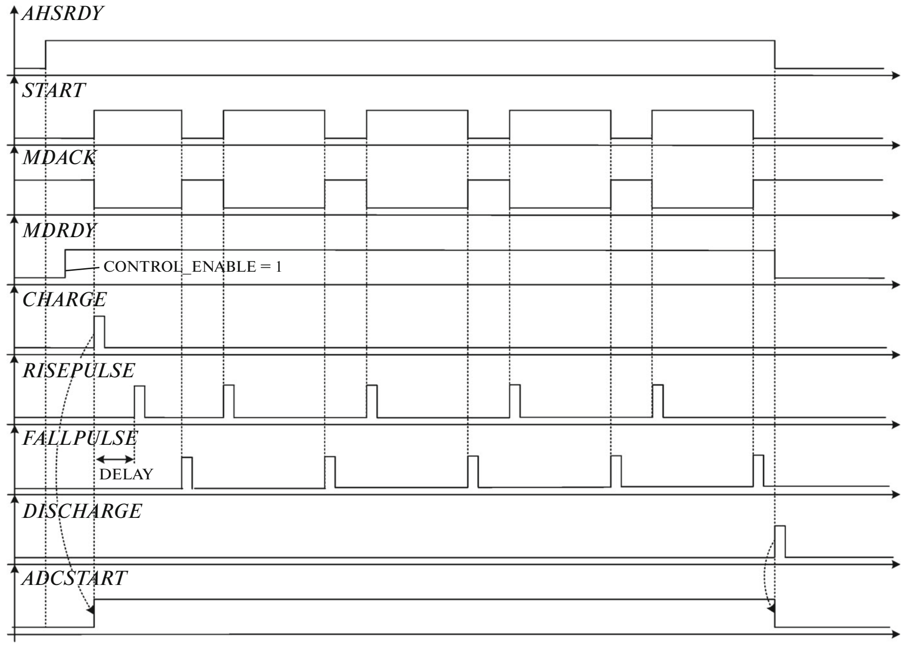

Fig. 4. Time chart of the *MCM* operation in the intrapulse modulation mode.

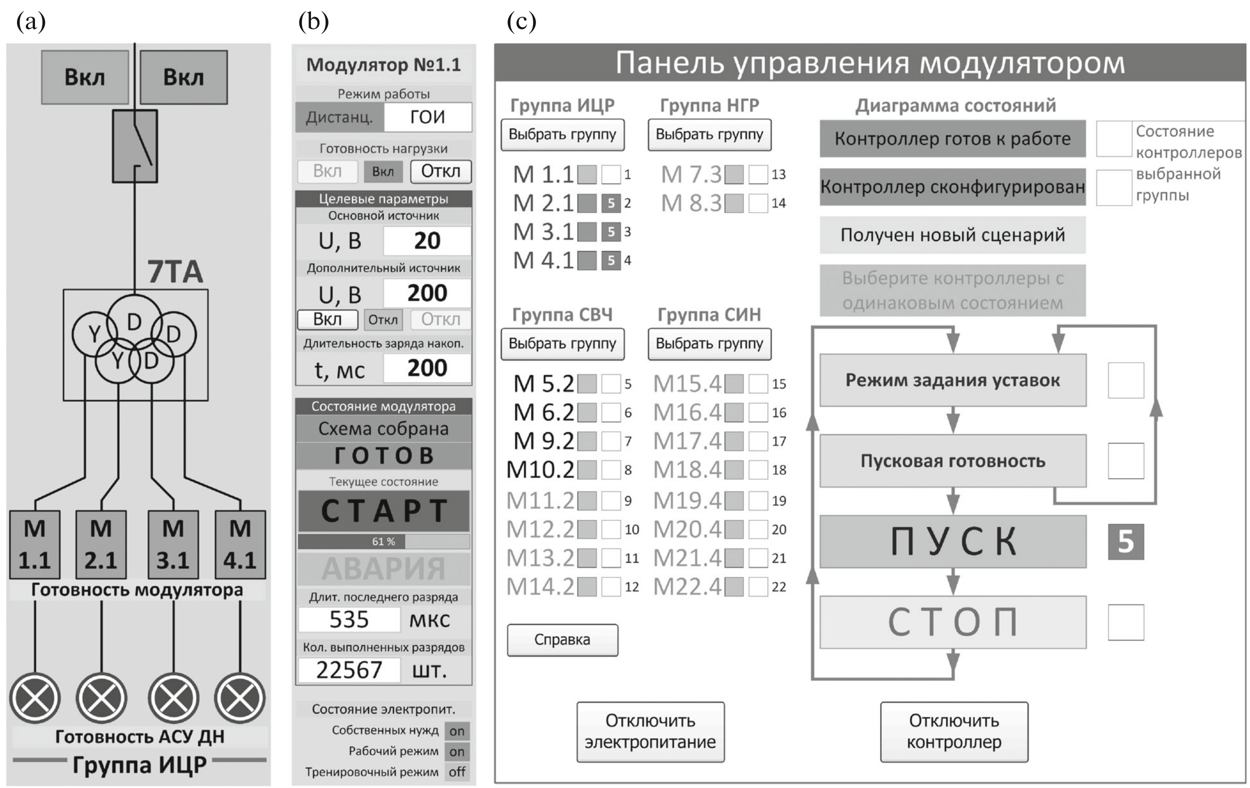

Fig. 5. Appearances of the graphical forms: (a) control and monitoring of the power supply of the modulators; (b) monitoring and input of modulator parameters into the MCU; (c) input of control commands of the MCU in accordance with the state diagram with consideration for admissible jumps. The designations on the panel of the auxiliary heating system: (IC) ion-cyclotron heating, (MCW) microwave heating, (LHR) low-hybrid resonance heating, and (INJ) injection heating.

and monitoring of the power-supply state of the modulators, entry of trimming parameter values for the modulator, monitoring of the state of the process equipment and the execution run of operator's commands. The user interface is constructed in the form of two zones: (i) process parameters (parameters of the experiment) and (ii) ACS parameters. In accordance with this sign, elements of the user interface are distributed over the screens of two displays. Additional frames (detailing frames) are switched in each zone individually.

To ensure the unfailing performance of the modulator control units, the software of the AEWS of the PMC calculates allowed states and monitor admissible jumps of the MCU to the new state. When errors in the equipment operation of the control system arise, the error is indicated and its code is displayed. In the local-control conditions, when the modulator is switched-off from the AEWS of the PMC, operator's commands are disabled, and the equipment state is only monitored.

CONCLUSIONS

The units of the designed ACS of the PMC allowed us to match the modernized control system and the power electrical equipment of the high-voltage modulator at the monitoring- and control-signal levels. The external interfaces of the control system are implemented in accordance with general-system requirements for the information-controlling system of the T-15 thermonuclear facility. At present, the control system was tested in a complex with the equipment of adjacent automation systems (ACS of the auxiliary heating system, central control system) and jointly with one high-voltage modulator, which was loaded into the gyrotron of the microwave-plasma heating system of the T-10 Tokamak (National Research Centre Kurchatov Institute, Moscow).

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