

SIMULATOR-ADVISER FOR SWITCHING OPERATIONS IN ELECTRICAL NETWORKS

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Clear skill and experience in switching operations by operators and operation managers are the corner stones of reliable work of the Russian Federation United Energy

System. Maintenance of this high-end skill at any level of operative and managerial control over the electrical networks is attained by persistent training with the help of specially designed simulator-adviser.

Keywords: electrical network, simulator-adviser for switching operations, switching operations planning, switching operations rules, personnel qualification.



Digital substations are the forefront of technological advancements in the area of power grids

INTRODUCTION

Multifunctional software system (MFSS) CASCAD is designed for automated solutions to a broad range of tasks emerging during operative and managerial controlling over the electrical networks and power-production plants [1, 2]. Initially, it was developed as a system predominantly focused on the operating mode tasks, although it also included the options for training the operating and managerial personnel to execute these tasks in power plants and systems [3, 4, 5]. Gradual expansion of the range of operating and training tasks resulted in the development of novel appends to MFSS structure, which implemented the functions responsible for switching operations in electrical networks in compliance to the requirements for these operations [6, 7]. It was assumed that these functions would be used to control the real switching operations and to train the operating personnel.

This problem had been solved by combining the results of the studies performed in Central Research Institute of Electric Power and then in R&D Center @ FGC UES on the control and planning of the switching operations in electrical networks with MFSS CASCAD. A line of simulators had been developed for switching operations such as TOP, OPTIMES, and CORWIN [8, 9, 10, 11, 12]. Specifically, these simulators implemented the sophisticated operation logical interlocking (blocking) based on formalized rules of switching technique. In addition, some R&D projects had been implemented on automation of planning of the switching operations [13, 14]. The models of control and supervision over the switching operations were integrated with the operating mode models [15 Ошибка! Источник ссылки не найден.; 16, 17] and with a human interface device ARCS [14, 18]. The gained experience was employed to integrate the

model of control and supervision over the switching operations with an operation mode dynamic model and a human interface device MFSS CASCAD.

PURPOSE AND BASIC FUNCTIONS OF SIMULATOR-ADVISER FOR SWITCHING OPERATIONS

The novel simulator-adviser has been developed for personnel training at any level of operative and supervisory control over the electrical networks. The purpose of training routines is to acquire knowledge and skills in executing the switching operations in the power electrical networks. Another important purpose of simulator-adviser is operative planning of the switching operations in the electrical networks and blocking supervision during execution of these operations. The developed simulator-adviser incorporated the functions of automated control (interlocking) of the switching operations and automated operational planning of these operations, which compiles the switching operation charts and programs.

Training and planning of switching operations are executed in a model of an electrical network. During these operations, the operation mode dynamic model implemented in MFSS CASCAD is employed.

The automated control with optional blocking of erroneous commands is performed with the use of formalized rules of logical interlocking of switching operations. These rules are specified as the formalized constraints for execution of switching operations specified in the technical regulations. If the program detects a mismatch

between issued command and the logical locking rules, the operator will receive the error message, while the operation will be blocked (fig. 1). The simulator-adviser always blocks the commands not enabled by the hardware interlocks such as interlocks of the disconnectors equipped with circuit breakers and grounding blade contacts.

The adjustment facilities of the simulator-adviser make it possible to implement the blocking control with the logical rules, which prevent the immediate critical consequences of the misoperations such as closing of the grounding blade contacts in the energized equipment. However, sometimes it is instructive to familiarize the trainees with possible severe consequences of such errors, and the intelligent interactive simulator-adviser can demonstrate the corresponding emergency situations.

Many rules of logical interlocking prevent not the emergency events per se, but the situations which degrade safety and reliability of the selected mode of operation. For such rules, either blocking or blocking-free control (accompanied only with message generation for the trainees) can be selected.

A special group of rules focuses on detection and control of the operating state of the equipment. These rules are employed during automatic control of the completion of switching operation tasks. In a formalized way, they specify such operative states of the power equipment as 'operating', 'under repair', 'under hot standby', etc.

Training of the power station personnel in switching operations is executed under automated control according to the switching locking rules and switching operation charts. A user can select any combination of these control methods such as 'by the rules only', 'by the charts only', or

A MESSAGE GENERATED BY SIMULATOR-ADVISER ABOUT THE ERROR DURING THE DISCONNECTION OPERATION

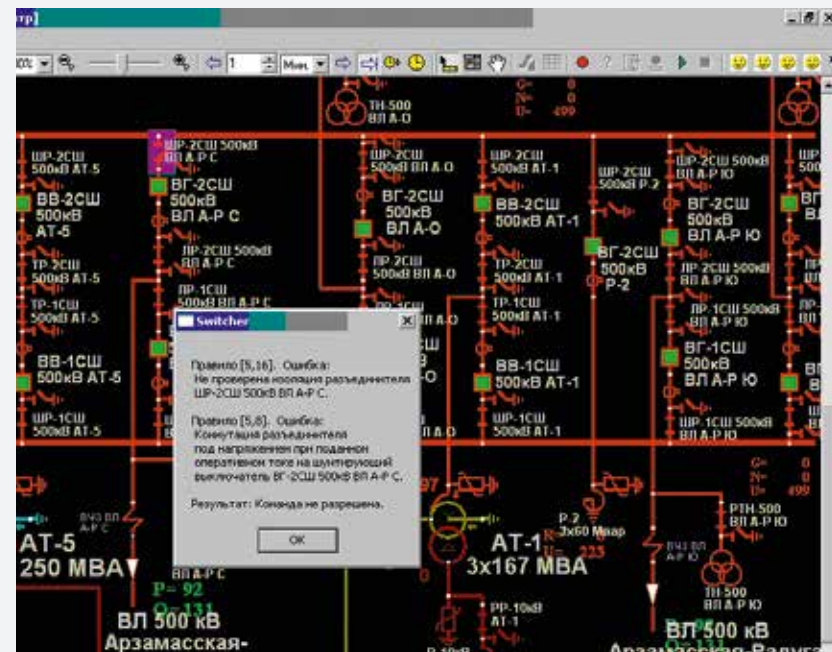


Fig. 1

'both by rules and charts'. When used for control over the training session, the switching charts are generated by automation tools of operative planning for switching operations available in the simulator-adviser.

PREPARATION FOR TRAINING AND SIMULATION OF SWITCHING OPERATIONS

Although the simulator-adviser is incorporated into MFSS CASCAD, it has its inner model of an electrical network. This model describes the network topology, state of the commutation devices, and the settings

of control equipment. Therefore, the simulator partially duplicates the major model of an electrical network incorporated into MFSS CASCAD. The inner model of electrical network of simulator-adviser is created and upgraded by automated conversion of MFSS CASCAD model of the electrical network. This conversion is triggered by user's command. To this end, the user should specify the list of substations and the connecting power lines.

The data on configuration of commutation devices are loaded from the major data base (DB) of MFSS CASCAD into simulator-adviser's DB immediately prior to training session or prior to simulation of the switching operations. These data can be obtained for MFSS CASCAD by different ways:

- by request from the operative DB of the information-control Supervisory Control and Data Acquisition (SCADA) system;
- by cyclic up-grading from SCADA operative DB;
- from the electrical network operation archive.

The current data transmitted from SCADA operative DB can be corrected in MFSS CASCAD according to the results of executed State Estimation task.

In present version of simulator-adviser the data on the current state and settings of protection and automation equipment are entered into its inner DB manually. In the following versions these data will be fed into simulator-adviser automatically from SCADA operative DB.

For each kind of training (and/or the task of simulation of the switching operations) two sets of data are formed, which describe: 1) initial state of all primary and secondary commutated devices in the simulation model; and 2) the current state of these devices. If a training (simulation) session is started from the very beginning, the first of these data sets should be loaded into the working area of simulator-adviser. In contrast, if the unfinished switching operations should be interrupted and then resumed, the current state of simulation model is saved in the second data set. This set is loaded into the working area of simulator-adviser automatically when resuming the interrupted switching operations. The training session can be stopped at any moment and resumed from the interruption point.

Generally, this is an outline of data preparation process needed for imitation of switching operations in simulator-adviser. Prior to beginning

DISPLAY OF THE TRAINING LOG WITH MESSAGES ON VIOLATION OF THE LOGICAL BLOCKING RULES

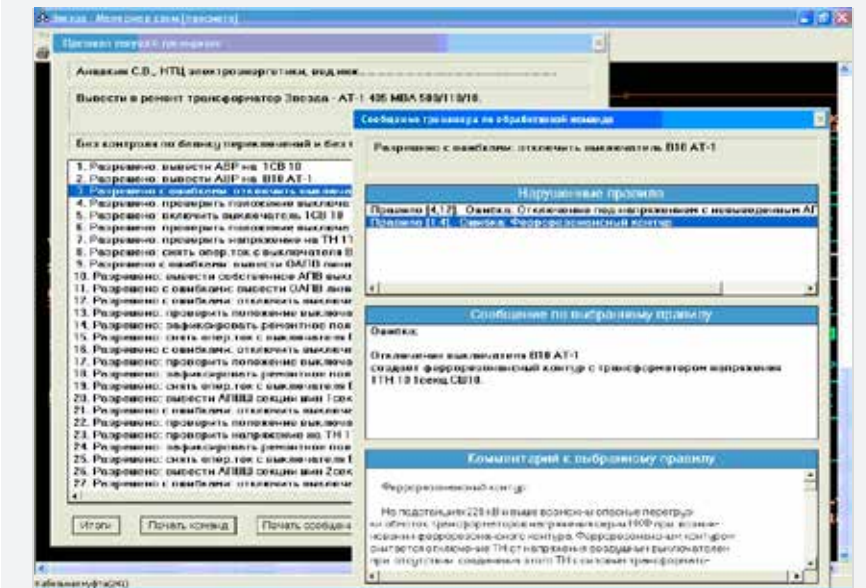


Fig. 3

of the training session with these operations, the user should also specify the following items:

- the aim of switching operations: electrical installation (power line, power (auto)transformer, bus section, switcher, or a network fragment) and the targeted operative state to be achieved by the installed equipment ('in operation', 'to be repaired', 'restore after emergency conditions', etc.);
- the type of operative control: 'by switching operation chart only', 'by the locking rules only', or 'both by locking rules and switching charts';
- the type of the responses to misoperations: blocking operations in response to all kind of mistakes or only to the most dangerous ones.

TRAINING WITH ANALYSIS AND ASSESSMENT OF THE GAINED SKILLS

The commands of switching and test operations are entered by user via a variety of menus, which correspond to the certain elements of the electrical scheme of the power plant or a substation (fig. 2). All the commands issued by a trainee as well as the responses of simulator-adviser are automatically recorded in the training log. If the training log window is open during the training session, the training process is reflected in this window by displayed user's commands and the simulator's responses (fig. 3). When needed, the user can evoke the detailed information about any issued command. If simulator-adviser detects a mismatch between

the issued command and the locking rules, the monitor will display the detailed information on the event. In the monitor, every violated rule will be accompanied with its content ('Message on selected rule' in fig. 3) and corresponding technical explanation in 'Commentary to the selected rule'.

If the training session is carried out under the control by a switching operation chart, the trainee can open the window of this chart and watch, which operations have been executed and which ones still wait in the queue (fig. 4). The unexecuted operations are marked with «-» symbol. After execution of the current operation, this symbol is replaced for «+».

The right part of fig. 4 shows the switching control chart window, while the left part of this figure shows the boxes, where the training options are selected.

At any moment of training session, the trainee can invoke information about execution of the current simulated task. To process such a request, the simulator-adviser employs the rules of control over machinery operative state. As a result, simulator-adviser generates a message which specifies the criteria of the simulated target state that have not been matched. If the training session is controlled by the switching operation charts, the trainee is also informed about the code numbers of unexecuted operations specified in this chart (fig. 5).

In addition, the same request displays the current statistical indices of the training session:

- the time spent for executed part of the training session;
- the total number of issued commands;

EDITING OF A SWITCHING CHART

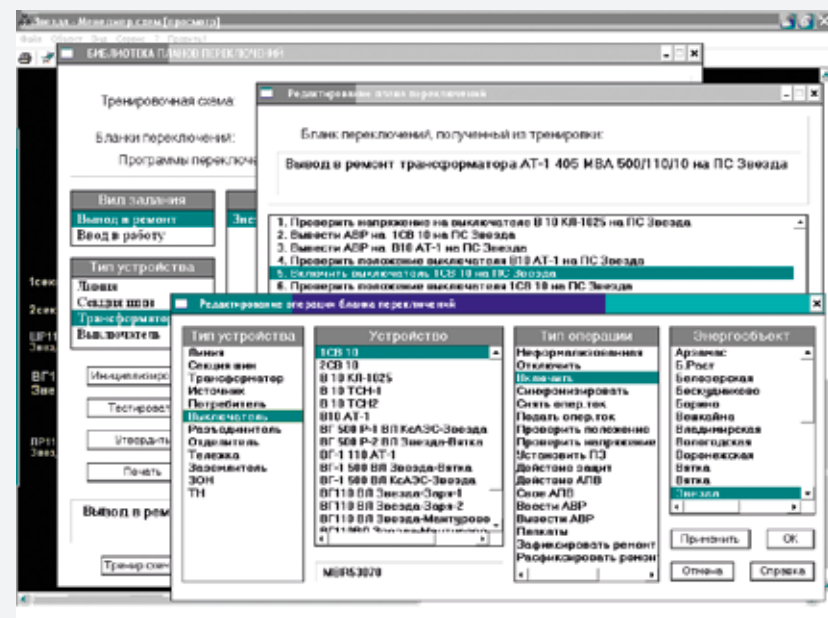


Fig. 6

- the number of erroneous commands;
- the number of safety-critical mistakes.

When the training session is controlled by the switching operation charts, the simulator-adviser also reports about the number of unexecuted operations specified in this chart.

GENERATION AND EDITING OF SWITCHING OPERATION CHARTS

The basic forms, which provide information on operative control over the switching operations are the switching operation charts and switching operation programs. In simulator-adviser MFSS CASCAD, the switching operation charts are employed to control the training sessions and to execute the real switching operations. The switch-

ing operation programs are considered as the generalized forms of the switching charts. The simulator-adviser possesses the tools for automated drafting the switching operation charts and switching operation programs based on the following principles:

1. Automatic generation of initial preform of the switching charts and programs.
2. Manual editing of the switching chart (program) preform with specialized editing program.
3. Testing of the resulting switching chart (program) with the logical locking rules.

The initial preform of the switching charts and programs can be obtained in two ways:

- By automatic deployment based on generic switching operations planning rules;

By 'cleaning' (editing) the log, which documented successful execution of the switching operations task.

In the first method, the user formulates the aim of planned switching operations, thereupon the automatic deployment of the chart (program) is performed based on the generic rules of the downstream planning of the switching operations. This procedure is executed via automatic refining of the generic operations related to the connection diagrams based on analysis of their topology.

In the second method, the switching operations task is executed in the training mode in compliance to the switching locking rules only. After successful completion of the task, the erroneous and blocked commands are removed automatically from the training log together with repeated and redundant pairs of the self-inverse switching operations.

The editor program of the switching operation charts (programs) can add, edit, or delete the commands. An example of combination of available dialog boxes is shown in fig. 6.

Testing of a switching operation chart is performed by its running in the training mode under the control of locking rules. If the chart is 'raw' with a large number of expected errors, the operation blocking is set only for the most dangerous errors. During final testing of a switching operation chart, the the operation blocking is enabled for all errors.

The procedure of interactive editing followed by testing the switching operation chart (program) should be repeated until elimination of all errors.

For automatic deployment of the switching chart (program) preform,

USER-DEFINED TYPES OF CONNECTION OF AN (AUTO)TRANSFORMER

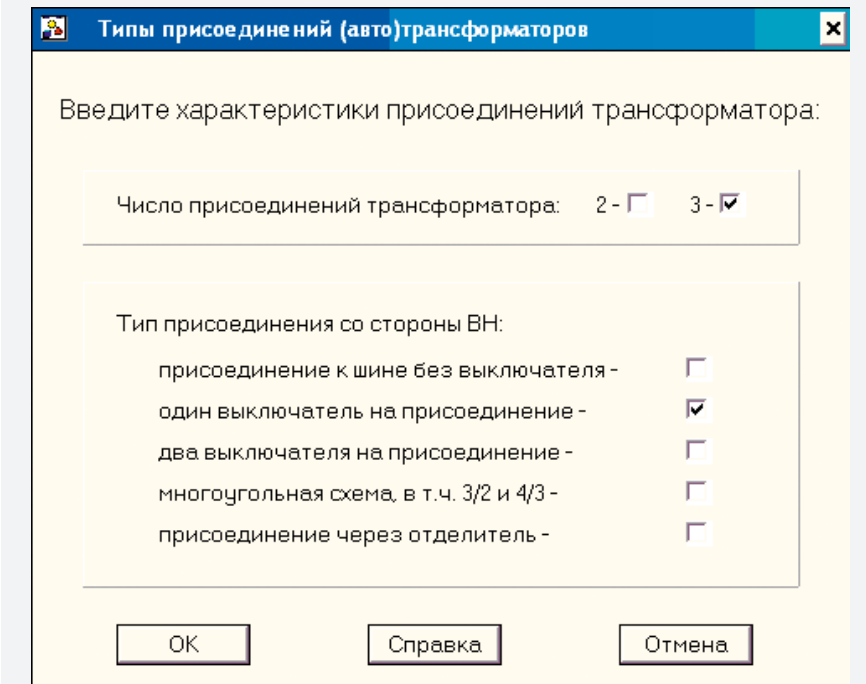


Fig. 7

the user should know the type of connection at each side of the device, for which the switching operation chart is to be generated. Here, a problem appears on automatic identification of the structural types of the device connection topology, i.e., the types of connection of the devices to the buses across the commutation hardware.

It should be noted that the substations of the Russian Federation United Energy System employ some non-standard connection schemes, which cannot be related to any topological type by means of logical definitions based on topology analysis. Therefore, recognition of the structural types of such connections cannot be fully algorithmized and automated. To solve this problem, the simulator-adviser implemented the combined method. Initially, the trial automatic recognition of the connection structural type is performed by analysis of topology of the scheme, thereupon the user is prompted to confirm or change the connection type revealed by the program (fig. 7). Thus, mutual control of reliable recognition of the connection topology type is performed on the basis of formal rules and human visual identification.

EDITING AND ADJUSTMENT OF SWITCHING RULES

The logic and technique of switching operations is formalized in the simulator-adviser as knowledge bases, which are the classes of formalized rules. There are three basic classes of such rules:

- the rules of logical locking;
- the rules of switching operation planning;
- the rules controlling the operative state of the machinery.

In each class, the rules are subdivided into the generic and individual (particular) ones. The typical rules specify the requirements of generic instructions on switching operations in the electrical networks [6, 7]. They are formulated in terms of device types without specifying the particular devices. Here is an example of generic logical locking rule: 'Switching of the loaded disconnecter without a shunt circuit is forbidden'. To apply such a typical rule, it should be automatically individuated and concretized on the basis of electrical network topology and related information available in the equipment data base. At this, the individual rules specify local and provisional conditions. Every individual rule refers only to one device in the electrical network. Concretization of a generic rule means its conversion into the individual rule.

In simulator-adviser, rules management system incorporates the facilities for input, editing, and adjustment of the rules. By its logical structure, the generic rules are far more sophisticated than the individual ones. In the considered version of simulator-adviser, the user is presented with adjustment options for some parameters of the generic rules, although without possibility of their comprehensive editing.

For individual locking rules, the simulator-adviser incorporates a complete multifunctional editor, which can determine any logical structure of the conditions in these rules.

This structure is designed in such a way that editor specifies the combination of the states of other devices, which enable (or disable) the particular operation for the given device in the

electrical network. Fig. 8 shows the editing procedure for individual locking rule via a dialog in the corresponding editor. Combinations of different modes to describe the conditions in the editor of individual rules makes it possible to specify any Boolean function formed by the logical connectives AND, OR, and NOT, which connect the variable device attributes.

In the current version of simulator-adviser, the generic logical locking rules are realized as the built-in procedures. Their number approximates to 150 (the the estimated number depends on the calculation method). The user can edit only some parameters of these generic rules. For instance, it is possible to change the value of a fine imposed by the simulator-adviser for violation of a generic locking rule. The user can also modify the list of operations controlled by a given generic rule, i.e. to remove this rule from a set of the generic rules that control an operation of one or another type (for example, the operation 'disconnect the switch') or to restore this rule in the set. Removal of a generic rule from a set controlling the operation does not interfere with the control over other operation types related to this rule (for example, 'Disconnect the breaker' or 'Turn off the grounding blade contacts off). Fig. 9 shows a set of generic locking rules, which control the breaker disconnection operation. The symbol '+' marks the enabled rules, while symbol '-' marks the rules that had been disabled by the user.

The user can specify the list of exclusions for any generic locking rule. To this end, the user marks the devices that should not be tested for compliance to the selected rule. If exclusion of a generic locking rule is specified for the given device, this rule will not be employed to control the operations executed by the device.

EDITING OF INDIVIDUAL OPERATION BLOCKING RULES

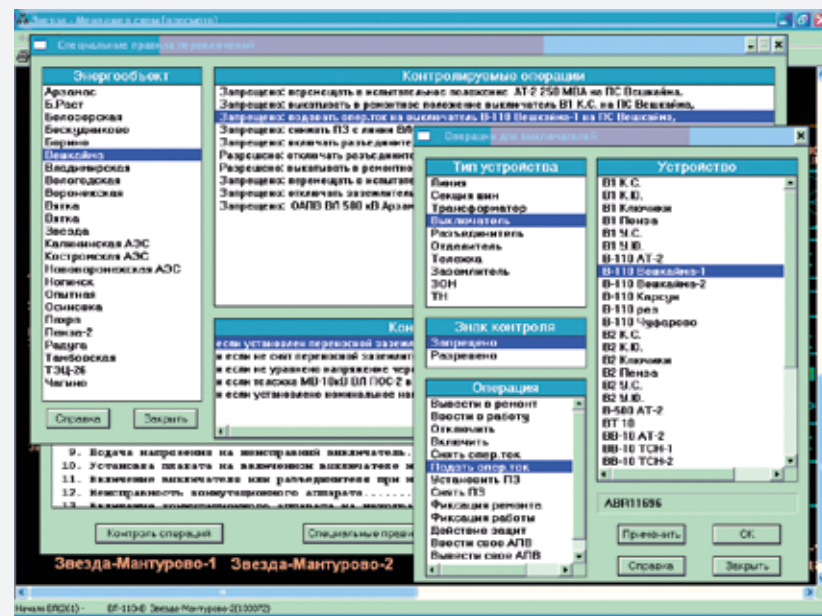


Fig. 8

ADDITION AND REMOVAL OF THE RULES TO AND FROM THE LIST OF TYPICAL OPERATION BLOCKING RULES

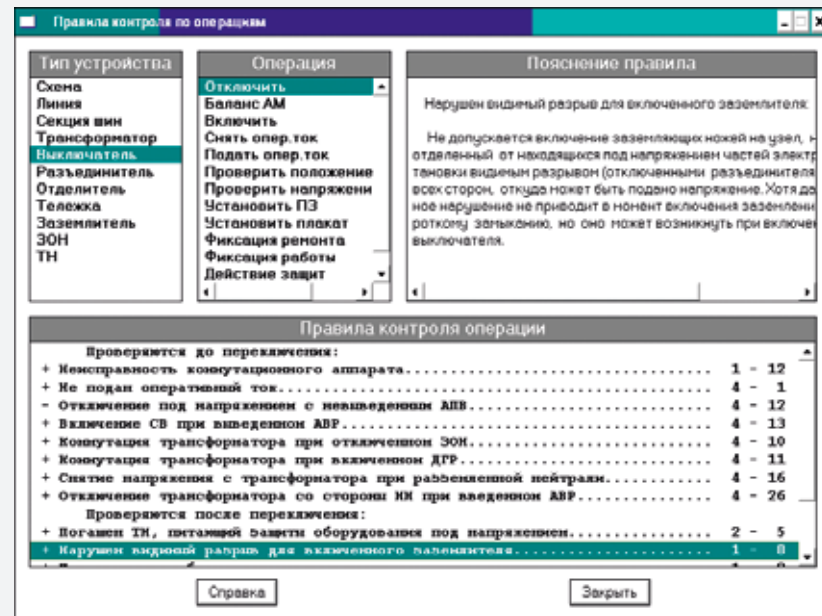


Fig. 9

Similar adjustment and editing facilities are available for the generic rules that control the operative state of the power plant equipment. Together they form an adaptable tool kit to specify the aims of switching operations. For training sessions and in planning the switching operations, the aim of operation is specified by the target electrical installation and by a set of criteria of the targeted state. The user can specify a set of generic criteria according to the type of planned switching operations ('put into repair', 'put into operation', etc.). When necessary, it is possible to enter additional individual criteria or exclusions from the generic ones.

SUMMARY

Simulator-adviser for switching operations in electrical networks based on EMS software CASCAD is described. As a simulator, it serves for training the personnel of power plants to execute the planned or emergency switching operations. As an adviser, it is designed to control (with the blocking options) the commands of operating personnel during operations with electrical network. During training, the automatic control of simulated commands is performed according to the rules of switching operations and previously elaborated switching operation charts (programs). The simulator-adviser incorporates an Editor of switching operation charts. This Editor generates initial preforms of switching operation charts and programs, while the user can edit them in the dialog boxes. The dialog functions can adjust the rules of switching operations in order to adapt the standard technical requirements to environmental, local, and provisional conditions.

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