On the issue of using a robotic manipulator to perform operational switching in electrical distribution devices and substations

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Abstract. During the operation of power supply systems, a sufficiently large number of labor cost of operational personnel is required to perform operational switching. The classification of operational switching has been considered in the article; conclusions have been made about the possibility of using robotic manipulators for some of them. A description of the design of this device and the functions that it should have has been given. A block diagram of the collection and exchange of information and control signals for the power supply system is presented, in which the robot manipulator automatically performs a certain set of manipulations according to a predetermined algorithm or at the command of an operator. Conclusions are drawn on the appropriateness of using these devices in substations with large room for installing switchboards.

1. Introduction
Today, the competitiveness of companies, especially energy companies, is unthinkable without the active use of unmanned technology. Remote execution of operational switching in electrical installations is one of the functions of operational dispatch control.

The use of robots to control equipment and devices of relay protection and automation of electrical substations can significantly reduce the time of equipment removal for repair, the time of output of relay protection devices for their maintenance, as well as their subsequent release for use, increase the safety of working conditions of staff, eliminating the possibility of exposure dangerous electric shock factors on it. This is especially true for remote electric grid facilities, where there is no year-round accessible transport infrastructure for access of operational personnel.

In addition, a great potential for reducing temporary labor cost for operational personnel lies in technical measures for preparing a workplace, assessing its safety, and access to work for an employee. At all stages, a person can be replaced by a robotic assistant.

2. Problem statement
The use of machine intelligence eliminates errors in the process of performing operational switching through the use of preset algorithms and switching programs. Additional self-test at each stage allows to increase the accuracy of the work performed. With the transition to a new level of operational-
technological control using robotics in the enterprise’s power system, controllability, observability will increase; the response time of the power system to emergency events will decrease.

3. Solution methods

Currently, the basic principles and procedure for switching are determined by order of September 13, 2018 N 757 “On the approval of the Switching Rules in Electrical Installations” developed and approved by the Ministry of Energy of the Russian Federation.

Operational switching in complexity is divided into complex, uncomplicated and simple. Complex ones are switching operations, accompanied by a large number of operations with switching devices and actions in relay protection and automation circuits. These include, for example: removal of the tire system, replacing the connection switch with a bypass switch, decommissioning the three-winding transformer at a substation with several transformers.

Simple switching is the decommissioning or commissioning of individual transformers, cable or overhead lines. Such types of work include switching associated with the disassembly (separation) of the circuit by disconnectors.

The simplest operational switching is switching off or on a single switch (without disassembling the circuit by disconnectors), switching in 0.4 kV networks; disconnect single connections in complete distribution devices.

Depending on the production need, switching can be scheduled, unscheduled, emergency. Scheduled - this is a switch, performed by pre-issued dispatch requests for the withdrawal or commissioning of equipment, the inclusion of new equipment. Unscheduled - this is a switch caused by the need to change the network mode to improve the reliability or efficiency of a particular circuit node (substation, distribution point, power plant).

Emergency switching is that necessary to eliminate the emergency mode, which poses a threat to the life and health of people, to a complex technological process. They consist in localizing the damaged system element, supplying power to the undamaged part of the system from a backup source.

Switching related to preventing the development or minimizing the possible consequences of the emergency mode (short circuit to ground in networks with isolated neutral, stopping part of the generators, shutting down an important transit line) can also be considered emergency ones.

The performance of all switching operations at large power facilities or electric networks is controlled by the operator, the switching operations are performed by the personnel serving this facility. Emergency shutdowns, switching, return to normal operation are often performed by a set of protective automation equipment after finding out the cause of the emergency event and do not require the participation of the operator to implement them.

After switching, all changes are included into the operational documentation: mnemonic diagram, operational journal, card or statement sheet, in the electronic database. All this is done manually, which carries the potential of using automation tools: when receiving information from a robot manipulator about performing any actions, all related information will be saved automatically, displayed on all available electronic circuits and maps.

A general view of the robot manipulator used for operational switching in electrical substations is shown in figure 1.

The possibility of their use is determined by the following prerequisites:

- recently, automation and digitalization of production has become a global trend;
- the transition from point to mass, systematic implementation of digital information transmission systems at power grid facilities begins;
- there is a deep integration of automated technological control systems at energy facilities.
- increasing requirements for the environmental friendliness of production, minimizing the harmful effects on the environment due to emergencies, they also require quick response to events that can cause damage.
Industrial robots are becoming more common in factories and enterprises [1-3]. They are used to carry out control, movement and movement functions in various production processes. Their main feature is that they do not get tired. Robots can work around the clock without any human involvement, because for their functioning you only need a laid program, according to which they will act. They can perform only certain actions, but most often they are used in automated production systems.

Thanks to the use of robots, it is possible to create a complete production cycle [4], which ensures productivity and accuracy at a very high level. In addition, errors in production due to the influence of the human factor are almost completely eliminated.

This article deals with the use of automatic devices, which are the simplest kind of robot manipulators. This variety is widely used due to their relatively low cost. They are widely used in enterprises for simple operations using the planned technology. In most cases, such devices do not have sensors. In this case, all actions are performed according to a cyclic program, which is pre-stored in the memory block.

The main design features and the principle of action is as follows [5,6]. Industrial robots, which have 6 joints, look like a human hand (shoulder, elbow and wrist). In most cases, the shoulder is mounted on a fixed base. As a result, such a robot can have 6 degrees of freedom, which means that it is able to move in 6 different directions. Like a human hand, the manipulator also moves the end effector from one place to another. When equipping the end effector with various devices (or tools), the robot has the opportunity to perform certain technological operations. One of the most common options is the similarity of a hand, which allows the robot to grab and move objects from place to place, turn the handles of operational circuits, control elements of power switching devices, and carry out rolling carts inside the distribution device.

For remote control over the manipulations of the robotic mechanism, it is advisable to equip it with additional cameras and position sensors in space (similar to those used in car parking systems). In case of violation of the regulations for carrying out the technological operation, a warning signal will first appear. If the robot does not respond to it, a command will be issued to terminate the operation and move the robot to a safe area. Duplicate signals about this emergency situation will be sent to the power system operator.

These sensors and video cameras will also allow to automatically receive a work permit. The prepared workplace will be visually compared with the template that will be laid down in the program of work of the robotic manipulator. He will navigate in space with the help of a points cloud attached to a single coordinate system obtained when compiling the 3D model of the distribution device (during design, followed by refinement upon the fact of construction or laser scanning).

The block diagram of the dispatch system based on the use of robot manipulators is shown in figure 2.
At the lower level (field level), all necessary technological operations are performed using robotic manipulators. The control signals and feedback signals from them are supplied by local controllers installed in the serviced buildings and premises of transformer substations and distribution devices. Next, the process of transmitting data to the server of the power supply system control system and to the control center (operator station) takes place. To increase the reliability of this system, it seems advisable to back up its individual elements (servers, channels for collecting and transmitting information).

The list of functional signals and information data transmitted by the robot manipulator the upper level:

- position of the robot in space;
- the position of the working bodies in space;
- service status signals (battery charge, faults in the power and control circuits);
- video data from the place of action;
- the position of the governing bodies of the switching apparatus of the distribution device, a conclusion on the correctness of their operation;
- the state of relay protection and automation devices, the presence of service or alarm signals on the front panels of these devices;
- operation of electricity meters;
- the presence of grounding devices, visual control of their position and reliability of contact;
- thermal imaging control of distribution device elements (switching devices, tyres, cable connectors, cable inserts, outgoing cable lines), room temperature control;
- monitoring of the state of surge arresters after their possible actuation;
- unauthorized entry of strangers into the room;
- the occurrence of emergency situations, the failure of any automated systems, visual control of the occurrence of smoke, flashes of light, open flame;
- data from an ultrasound scanner that records noise at high frequencies, which are signs of deterioration in the state of insulation (installed optionally).
In addition, the functions of the robot manipulator should include “hot swapping” of individual functional blocks that technologically have such an opportunity (for example, replacing retractable block modules with circuit breakers with small weight and size characteristics).

4. Conclusions

The introduction of robot manipulators to perform operational switching, as expected, at the initial stage will not be a budget event. Therefore, it is advisable to consider the point-wise application of these devices in those facilities where there are sufficiently large, long distribution devices installed in one hall (room). Such objects may include distribution device at a voltage of 10 kV substations of class 110/10 kV and higher. At the first stage, during the development and pilot use of robot manipulators, an increase in labor costs is expected on the part of support stuff, as well as service organizations for maintenance and debugging the robot. But it is expected that in the future its use will lead to a reduction in the complexity and share of manual labor in carrying out technological operations and processes, and as a result, an increase in controllability and a reduction in the response time of the power system to emergency events and planned events at the enterprise. The use of robot manipulators will be a new stage in the development of Russian energy systems [7], contribution to the creation of conditions for the mass introduction of innovative solutions that will lead to the significant increase in the efficiency of the Russian energy sector and, as a result, increase the competitiveness of the Russian economy.

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