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Monitoring the Number and Duration of Power Outages and Voltage Deviations at Both Sides of Switching Devices

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ABSTRACT The need for monitoring the electrical network parameters is identified to use methods and means to improve power supply reliability and power quality. The article lists the exiting sensors for monitoring electrical parameters and substantiates the necessity of monitoring the parameters at both sides of switching devices. In the paper, there is basic information on the structure, operation and capabilities of the monitoring system for power supply reliability and power quality. A functional electrical circuit of the device for monitoring the number and duration of power outages and voltage deviations is proposed for monitoring the parameters at both sides of switching devices. An algorithm for the device operation has also been developed, which allows detecting the main emergency modes in the consumer's internal network. The article also describes laboratory tests of a prototype of the device for monitoring the number and duration of power outages and voltage deviations, which is based on the Arduino NANO V3 ATmega 328 microprocessor.

INDEX TERMS Power supply system efficiency, power supply reliability, power quality, power supply restoration time, power quality inconsistency time, monitoring system, Arduino prototype, laboratory tests.

I. INTRODUCTION

Ensuring a reliable supply of high-quality electric energy to consumers is a difficult but necessary task since it is currently impossible to imagine the normal functioning of consumers (from manufactures to homeowners) without electrical energy usage. Therefore, the main parameters of the power supply system efficiency are power supply reliability (PSR) and power quality (PQ) [1], [2].

In turn, power supply reliability mainly depends on the restoration power supply after failures [3]. A comprehensive review on the major power supply outages made in the article [4] proves the importance of reducing power supply restoration time due to the enormous losses arising in the social, economic and political spheres. Many scientific works are devoted to the problem of power supply restoration in different areas and propose methods to reduce its time. So, in the article [5] power supply restoration is proposed to be reduced by leveraging microgrids. In the paper [6] authors suggest a multi-stage restoration method for the MV power system with distributed generation. The method is to combine distribution grid islanding with network reconfiguration to minimize the number of deenergized consumers. A heuristic method for distribution network restoration is presented in the paper [7], a parallel automated resilience-based restoration methodology is in paper [8]. There are many proposed algorithms for power supply restoration, for example, based on Wasserstein distance metric [9] or Artificial Bee Colony optimization [10].

Scientists also do not bypass the issues of improving the quality of electricity and a very large number of works are devoted to methods to reduce power quality inconsistency

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time. The paper [11] presents an optimal power control strategy for an autonomous microgrid operation based on a real-time self-tuning method. The paper [12] proposes the Pareto optimization methods to minimize of voltage deviations and power losses. In the paper [13] authors use Artificial Neural Network to mitigate the effects of the power quality problems arising out of voltage dips. The paper [14] focuses on introducing the coordinated voltage control technique for solving a voltage quality problem.

Also, there is a large number of already developed means for increasing PSR and PQ, for example, systems for regulating electrical power quality parameters (for example, adaptive automatic voltage regulation [15]), transformer substation automation systems (Automatic Transfer Switches (ATS), automatic circuit reclosers (ACR) [16], under-frequency load shedding (UFLS), buses' load balancing [17]), systems of automatic regulation (compensation) of reactive power [18], [19].

At the same time, the implementation of these means as well as using methods for increasing PSR and PQ, including ones mentioned above, requires monitoring the electrical network parameters in order to accurately and quickly respond to any changes in a power supply system [20]. In addition, such a monitoring system, even without other technical means of increasing power supply reliability, can reduce some constituents of the power supply restoration time via quickly obtaining and analyzing failure signals by a dispatching office [21]. It affects power supply efficiency on the good side as well.

The current examples of the monitoring systems are based on different devices and approaches. Among devices, power measurement units (PMUs) can be distinguished. PMUs allows accurately and quickly measuring the magnitude and phase angle of voltage and current in a power grid. The paper [22] investigates the problem of line outage detection by using PMUs. It proposes a method differentiating slowly changing loads and abrupt changes introduced by external line outages. The paper [23] describes a technique to detect and isolate the outages of electrical transmission lines (ETLs) in near real-time. The work is based on a survey on the theory of quickest change detection (QCD) [24] and gives a QCD algorithm for ETL outage detection as quickly as possible subject to a constraint on the false alarm rate. One more algorithm using PMUs to detect multiple line outages at the complexity of solving a sparse signal reconstruction problem is presented in [25]. The article [26] also proposes an algorithm trying to solve identifying multiple line outages problem. The presented Estimation of Distribution (EDA) algorithm has outperformed other state-of-the-art algorithms such as binary particle swarm optimization, adaptive and genetic ones. Despite accurate and quick measuring of electrical parameters, PMU has a significant drawback – it is expensive. It is why they are applied at transformer substations in large power grids of high and medium voltages. All works, considered above, used PMUs for identifying power supply outages at outgoing ETLs. This drawback of PMU is mentioned in [27]. The paper describes the framework for Wide Area Measurement System (WAMS) and optimizes the number of measurement devices including PMUs for the considered system. It should also be noted that in some cases PMUs may not accurately reflect the true relationship between ETL outage and the observed angle changes, which could lead to errors in detecting outages [28].

The accuracy of power supply outages can be increased by using sensors installed at different electrical network points. Such devices like [29], [30] allow being installed at any section of power lines and transmitting data on measurements of current, temperature and line sags.

Furthermore, the efficiency of monitoring systems will be much increased by using sensors at electrical network endpoints. There are many commercial ones manufactured by leading world companies and not only. However, scientific work does not stop in this direction. For example, the paper [31] proposes the device to monitor frequency and voltage. The device is based on Raspberry Pi Model 3b with adequate UPS. The pros of the device are that it can exchange information via Ethernet and Wi-Fi network and additionally via GSM using the external card. The work in [32] is aimed at creating a cloud-based power failure sensing system to enable automatic power failure sensing and reporting as well as monitoring the LV power network. The main elements of this system are sensors based on Arduino microcontroller. The electronic devices are able to detect the power supply outages and send the adequate alert messages to the mobile phones of the power supply personnel and cloud application. The system allows power supply service personnel to take quick measures to reduce power supply restoration time.

A great option is to use smart meters as sensors of electrical parameters at network endpoints (and at other points as well). Based on smart meters it is already possible to launch Advanced Metering Infrastructure that allows for not only automated reading of electricity consumption and also the transmitting data on it along with other electrical parameters to power supply companies for further processing [33], [34]. There are papers devoted to using metering infrastructure for detection power supply outages. The paper [35] presents the possibility to use the information provided by AMR system, including the on-demand read feature, to develop a polling procedure to identify system conditions. This paper presents a general polling algorithm for confirming restoration without polling all of meters in the entire network. In the work [36] a power outage management system is developed on the basis on using smart meters. The proposed solution is realized on Mitsubishi Electric Corporation in-house smart grid demonstration facility. A similar contribution as in the previous article was made in [37], but the focus was on the LoRaWAN wireless data technology. The paper explains how LoRaWan can be employed in the polling algorithm for outage management system using metering infrastructure.

Despite the great work done by scientists and industrial companies, the existing systems for monitoring electric network state have areas for improvement. So, the considered above devices not allow for electrical parameters' monitoring on both sides of a switching device, although it is necessary to distinguish failures in inner or external networks at monitored points. Certainly, it can be done through the use of two devices installed on different sides of a switching device, but it significantly increases the cost of such monitoring. In addition, it does not eliminate the need to configure (program) these devices to analyze the registered electrical parameters and send the corresponding signals to an electrical grid company for further processing. In this article, the proposition for a device with such possibility is presented. It has implemented the method to measure voltage at the input and output of a switching device and then sending signals to SCADA in accordance with the proposed algorithm. The operation algorithm of the device allows detecting such the emergency modes as voltage deviation, overload and short circuit in the internal network as well as power supply outage in both internal and external networks.

It gives an opportunity for SCADA to detect emergency modes in electrical networks under monitoring via analyzing the signals obtained from all devices including their combination and sequence. In addition, such signals make it possible to identify emergency mode causes and identify a culprit. Thus, the important element of this article is a proposition of operation algorithm laid down in the devices for monitoring electrical parameters at both sides of a switching device.

The article is organized as follows. Section 2 presents the concept of a system for monitoring power supply reliability and power quality. Section 3 contains the proposition of key device of the system, that is a device monitoring the number and duration of power supply outages and voltage deviations. Section 4 presents the implemented algorithms to the device. Section 5 contains the discussion of the results and future directions of the research. Section 6 is a conclusion part.

II. SYSTEM FOR MONITORING POWER SUPPLY RELIABILITY AND POWER QUALITY

In [16] there is the concept of the system for monitoring power supply reliability and power quality (SMR&Q) based on sensors for monitoring electrical parameters at both sides of a switching device - devices for monitoring the number and duration of power outages and voltage deviations (DMPO&VD). These sensors are installed at the consumers' inputs, at the outgoing electrical transmission lines (ETL) and at the low voltage (LV) buses of a transformer substation (TS).

The monitoring system for power supply reliability and power quality is built on a hierarchical method and works as follows (Fig. 1). Information from each consumer of electricity and other electrical network points by means of DMPO&VD via the communication channel is collected at an aggregation point - Data Acquisition and Transmission Devices (DATD). Each DATD is responsible for a certain number of DMPO&VDs located in one area. Further, the information through the main communication channels goes to the dispatching office of an electrical grid company (DEC), where the data is analyzed and a decision is made

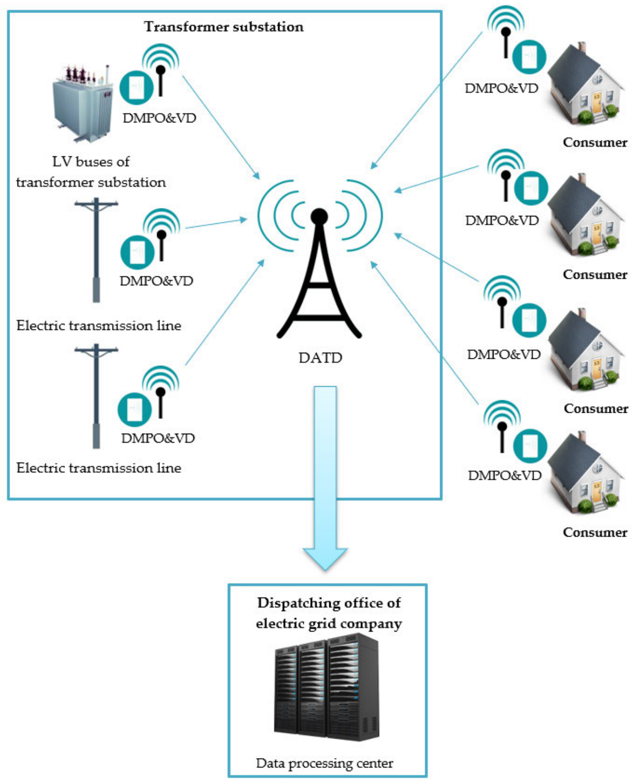

FIGURE 1. Structural diagram of the system for monitoring power supply reliability and power quality.

to eliminate the existing malfunction including the need of voltage regulation as well as sending a repair team.

As data transmission channels between DMPO&VD and DATD, it is possible to use only wireless data transmission technologies, such as GSM, NB-IoT and LoRa [38], [39]. The use of wire channels (NB-PLC, Fiber-optic communication, DSL) is not advisable due to the fact that SMR&Q should detect not only power supply outages in a network, but also the wire breakage of power lines, which as a rule can occur along with the information wire breakage.

SMR&Q built on DMPO&VDs and receiving signals from them allows detecting the emergency modes of the electrical network and their causes, listed in Fig. 2.

III. CONCEPT OF THE DEVICE FOR MONITORING THE NUMBER AND DURATION OF POWER SUPPLY OUTAGES AND VOLTAGE DEVIATIONS

The functional circuit of the original device that monitors the number and duration of power supply outages and power quality (DMPO&VD) was presented in [16]. The structure of this device has been modernized to increase its technical capabilities. A distinctive feature of the upgraded DMPO&VD is the use of 2 voltage sensors, which allows for voltage monitoring before and after a switching device. This makes it possible to realize the detection of power outages in a consumer's internal network. The functional circuit also

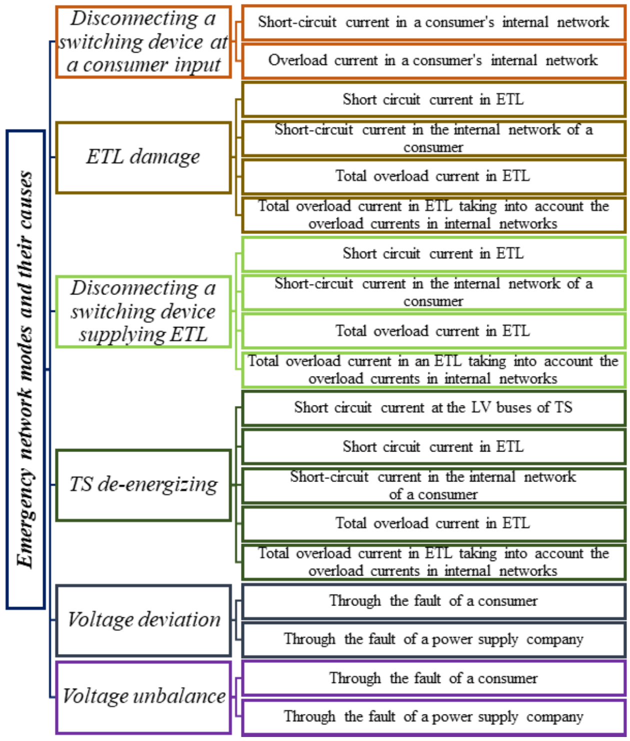

FIGURE 2. Emergency network modes and their causes.

provides the ability to receive data from the DEC. It allows using feedback to analyze the status of the system and providing the necessary information to consumers, and if necessary, executing certain commands. The upgraded DMPO&VD also includes an archive data storage device used in case of a violation of the communication channel with DEC. The functional electrical circuit of the upgraded device is presented in Fig. 3.

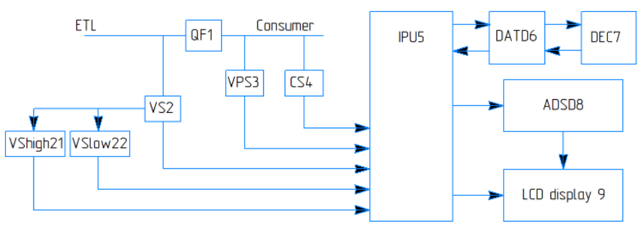

FIGURE 3. Functional circuit of the device for monitoring the number and duration of power supply outages and power quality.

The elements of the functional circuit are: QF1 is circuit breaker (switching device), VS2 is voltage sensor, VPS3 is voltage presence sensor, CS4 is current sensor, IPU5 is information processing unit, DATD6 is data acquisition and transmission devices, DEC7 is the dispatching office of an electrical grid company, ADSD8 is archive data storage device, LCD display9, VShigh21 is high voltage sensor, VSlow22 is low voltage sensor.

The proposed functional circuit of DMPO&VD allows detecting the main emergency modes occurring in the consumer's internal network (or at other points they are installed): power supply outage, voltage deviation (VD) below and above the permissible level, overload and short circuit in the consumer's internal network. The DMPO&VD also register power supply outage in an external network. Based on the signals received from DMPO&VDs as well as their sequence and combinations, SMR&Q will be able to detect the emergency modes already in the entire electrical network under monitoring and the causes of their appearance.

IV. THE ALGORITHM OF THE DEVICE FOR MONITORING THE NUMBER AND DURATION OF POWER SUPPLY OUTAGES AND VOLTAGE DEVIATIONS

Accurate emergency mode detection by SMR&Q is possible only by obtaining comprehensive information from all DMPO&VDs installed in the electrical network under monitoring. Therefore, it is necessary to develop an operation algorithm of the device for monitoring the number and duration of power supply outages and voltage deviations. This algorithm should allow detecting emergency modes in an internal network, transmitting signals about it to the DEC and providing information on the possible causes of these emergency modes. Figs. 3 - 7 show the algorithm of DMPO&VD operation according to these remarks.

In normal mode, the algorithm operates as follows. The algorithm starts from the block 1 "Start" (Fig. 4). Overload current I_{OL} and short circuit current I_{SCT} are initialized in the block 2. The block 4 is used to check the condition "$\delta U_{(-)} \geq 95\%$". If voltage is present in the network, the condition is

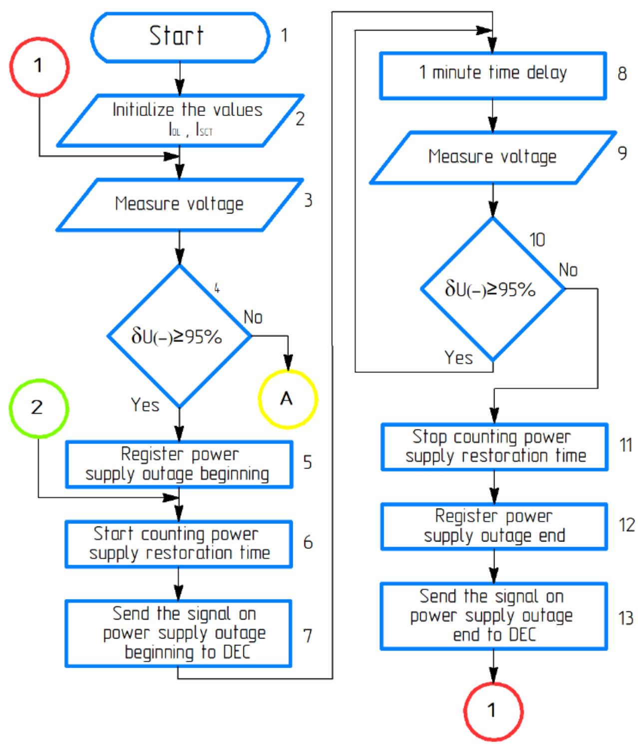

FIGURE 4. The beginning of DMPO&VD algorithm. Monitoring power supply outages.

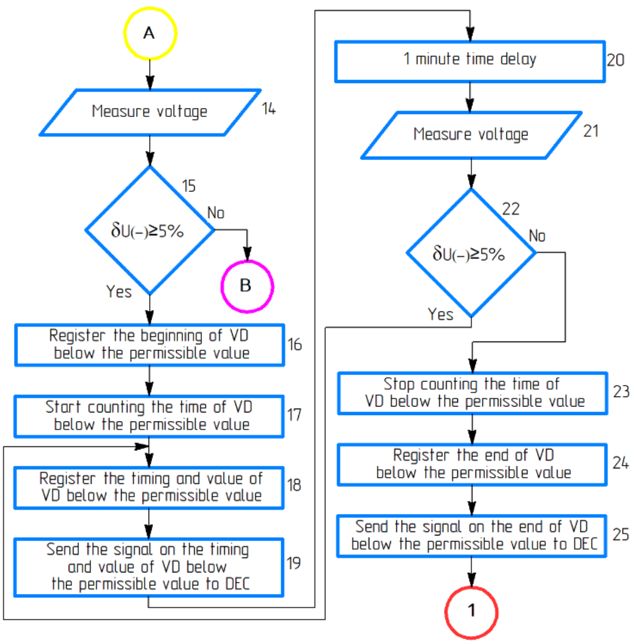

FIGURE 5. **The continuation of DMPO&VD algorithm. Monitoring voltage deviation below the permissible level.**

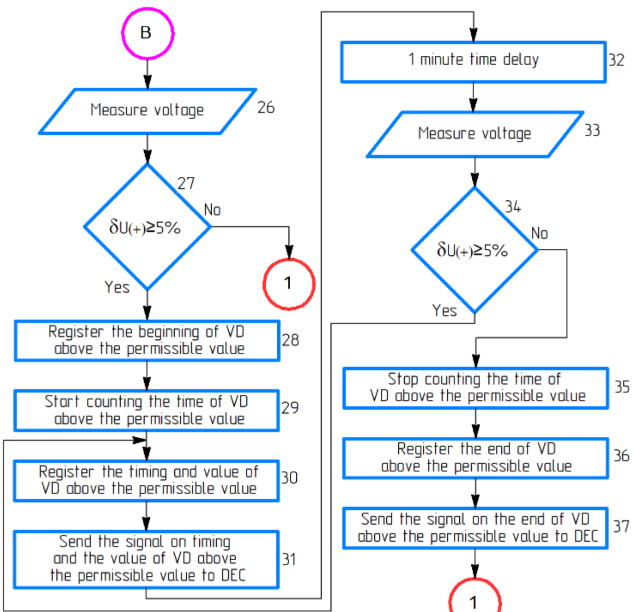

FIGURE 6. **The continuation of DMPO&VD algorithm. Monitoring voltage deviation above the permissible level.**

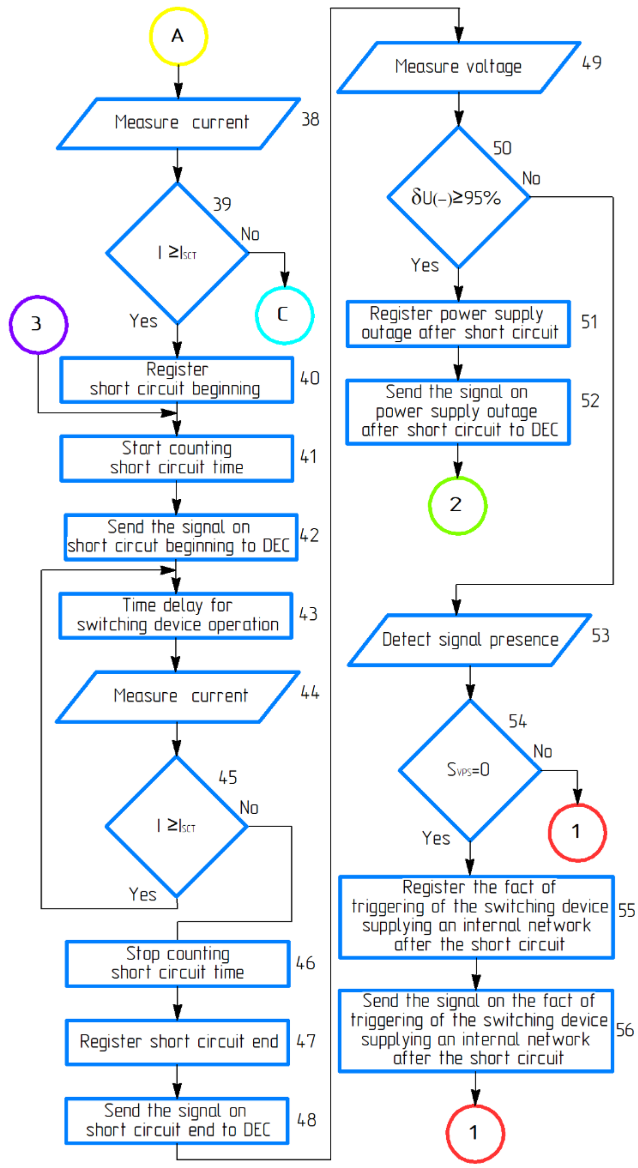

FIGURE 7. **The continuation of DMPO&VD algorithm. Monitoring short circuit in the internal network.**

not satisfied and the algorithm switches to parallel measuring voltage (Figs. 5 - 6) and current (Figs, 7 - 8). Checking for voltage deviations below and above the permissible level is performed by the blocks 14, 15 and 26, 27 respectively. If the condition of the block 15 ("$\delta U_{(-)} \geq 5\%$") is not satisfied, that is the voltage deviation below the permissible level is not detected, the algorithm proceeds with checking for the condition of the block 27 ("$\delta U_{(+)} \geq 5\%$"). And if this condition is not met, the algorithm ends the cycle and returns to the block 3. Checking for overload and short circuit current is performed by the blocks 38, 39 and 54, 55 respectively. If the current does not exceed the short-circuit current value, the condition laid down in the block 39 is not fulfilled ("$I \geq I_{SCT}$") and the algorithm proceeds with checking for overload current in the block 55 ("$I \geq I_{OL}$"). If this condition is not met as well, the algorithm ends the cycle and returns to the block 3.

If voltage outage occurs in the network, the condition of the block 4 (Fig. 4) will be met and the algorithm will run blocks as follows. The block 5 will register the fact of power supply outage in the memory of the DMPO&VD (in the archive data storage device), the block 6 will start counting power supply restoration time and then the block 7 will send the signal on it to the dispatching office of an electrical grid company. Then, the voltage will be measured again (the block 9) with a delay of 1 minute (the block 8). The condition of the block 10 is identical to the condition of the block 4, that is, checking for the presence of voltage. If the condition of the block 10 is fulfilled, the algorithm returns to the block 6. At this time, there is no need to check for voltage deviation, short-circuit current and overload current since these conditions will never be met without voltage presence. Thus, the algorithm will be looped with checking for the voltage presence every minute. As the voltage appears, the condition of the block 10 is not be met and the algorithm continues its work. The block 11 will stop counting the power supply restoration time, the block 12 will register this count in the DMPO&VD memory, and the block 13 will send the signal on it to the DEC. Next, the algorithm returns to the block 3 for a new cycle. Thus, this algorithm will allow registering both the start and end time of power supply outage in the device memory and send this information to the DEC for further processing.

The voltage check for deviation below the permissible level is carried out by the block 15 (Fig. 5). As soon as a voltage deviation below 5% occurs in a network, the condition "$\delta U_{(-)} \geq 5\%$" will match and the block 15 will start the following part of the algorithm. The block 16 will register the fact of a voltage deviation below the permissible level in the memory of DMPO&VD, the block 17 will start counting the time of this deviation. Then the block 18 will register the timing and value of VD below the permissible level in the memory of DMPO&VD and the block 19 will send this information to the DEC. After that, there will be the delay for 1 minute (the block 20) and the block 21 will start the next voltage check for deviation below the permissible level, the block 22 will check for this condition. If the condition "$\delta U_{(-)} \geq 5\%$" is fulfilled, the algorithm will return to the block 18. The timing and value of VD below the permissible level will be registered again and send to the DEC. As soon as the condition of the block 22 is not fulfilled, the device will register that voltage has returned to the range of acceptable values and the algorithm will continue to work as follows. The block 23 will complete counting the time of VD below the permissible level, the block 24 will register this fact in the DMPO&VD memory, and the block 25 will send the signal on it to the DEC. Next, the algorithm returns to the block 3 for a new cycle. Thus, the device and DEC will receive not only information on the beginning and end of VD below the permissible level, but also information about the level and duration of this deviation.

The voltage check for deviation above the permissible level is performed by the block 27 (Fig. 6). As soon as voltage is more than the permissible level by 5%, the condition "$\delta U_{(-)} \geq 5\%$" will matches and the block 27 will start algorithm blocks identical to the algorithm blocks for detecting VD below the permissible level. These blocks will allow registering to the archive data storage device and send to the DEC the information about the beginning and end of the voltage deviation above the permissible level as well as the information about the level and duration of this deviation with the accuracy of 1 minute.

Regardless of checking the voltage for deviations below and above the permissible level, the algorithm allows the DMPO&VD to check for short-circuit and overload currents. Checking for short circuit current is as follows (Fig. 7). The block 38 starts the current measurement and the block 40 register the beginning of short circuit in the internal network when fulfilling the condition "$I \geq I_{SCT}$" of the block 39. The block 41 will start counting the short circuit time and the block 42 will send this information to the DEC. After the appearance of the short-circuit current, it is necessary to withstand the time for the switching device to operate, which will be performed by the block 43. After that, the next check for short current will be performed by the blocks 44 and 45. The algorithm will loop and return to the block 43 until the short-circuit current disappears. Upon the disappearance of the short circuit, the condition "$I \geq I_{SCT}$" of the block 45 will not be met, the block 46 will stop counting the short circuit time, the block 47 will register this fact, the block 48 will send this information to the DEC. The disappearance of the short circuit current can be due to the following causes:

1) The removal of the short-circuit cause without switching operations - the external network is functioning, the consumer continues to receive electricity;
2) Disconnecting the switching device supplying the consumer's network - the consumer is de-energized, the external network is functioning;
3) Non-selective disconnection of the switching device supplying the power line - the external network and the consumer itself are de-energized.

Accordingly, there are 3 options for continuing algorithm operation. For this, the algorithm starts the block 49 for measuring voltage and the block 50 for checking the condition for voltage in the external network ("$\delta U_{(-)} \geq 95\%$"). If the condition is met, DMPO&VD registers power supply outage after a short circuit in the consumer's internal network with the help of the block 51 and transfers this information to the DEC with the help of the block 52. Next, the algorithm proceeds with the block 6 (Fig. 4) to register the duration of this outage. It should be noted that in this way the device allows registering power supply outage after short circuit current. The non-selective disconnection of the switching device supplying the power line due to this short circuit current can be determined only in the DEC after analyzing signals of other DMPO&VDs installed in the electrical network under monitoring.

If the voltage in the external network is present, the condition of the block 50 are not fulfilled and the algorithm starts the verification procedure of disconnecting the switching device supplying the internal network. For this, the block 53 starts checking for the presence of a signal from the VPS (voltage presence sensor), and if it is absent, the condition of the block 54 ("$S_{VPS} = 0$") will be met, and the block 55 will register the fact that the switching device has tripped after the short circuit. After sending this information to the DEC

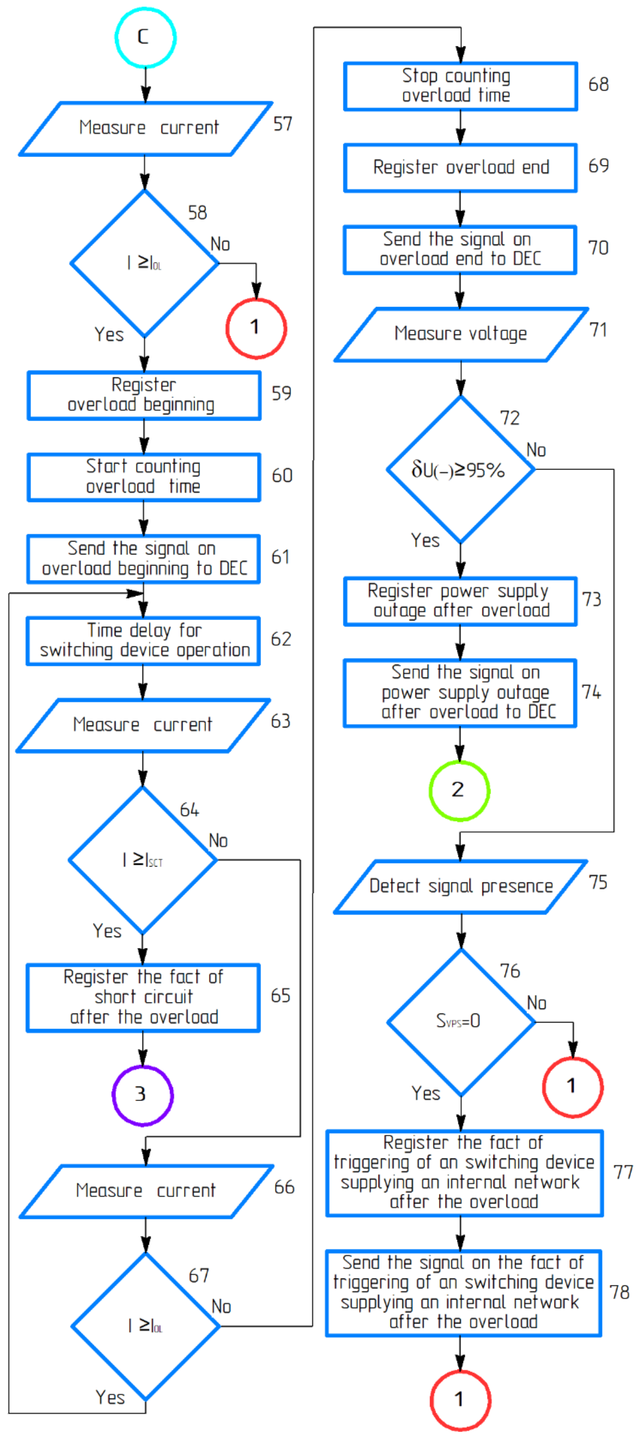

FIGURE 8. **The continuation of DMPO&VD algorithm. Monitoring overload in the internal network.**

by the block 56, the algorithm returns to the block 3 (Fig. 4) for a new cycle. In case the condition of the block 54 does not match (voltage after the switching device is present), the algorithm proceeds straight with the block 3.

Checking for the overload current is carried out if the condition of the block 39 is not fulfilled (Fig. 7). In this case, the block 57 (Fig. 8) starts the current measurement, the block 58 checks for the condition of the presence of an overload current ("$I \geq I_{OL}$"). When the condition is met, the overload current in the internal network is registered (block 59), the time counts from the moment of overload (block 60) and a signal on it is sent to the DEC (block 61). After a delay in the operation of the switching device (block 62), a sequential check is made for short-circuit current and overload current (blocks 63, 64 and 66, 67, respectively). Check for short-circuit current is done in order to register a short-circuit, which is the consequence of the overload current.

In this case, the condition of the block 64 will be fulfilled, the block 65 will register this fact and the algorithm will

TABLE 1. **Signals from DMPO&VD.**

N	Signal	Meaning
1	"Beginning $\delta U_{(-)} \geq 95$ %"	Beginning of power supply outage in an external network
2	"End $\delta U_{(-)} \geq 95$ %"	End of power supply outage in an external network
3	"Beginning $\delta U_{(-)} \geq 5$ %"	Beginning of voltage deviation below the permissible level
4	"End $\delta U_{(-)} \geq 5$ %"	End of voltage deviation below the permissible level
5	"Beginning $\delta U_{(+)} \geq 5$ %"	Beginning of voltage deviation above the permissible level
6	"End $\delta U_{(+)} \geq 5$ %"	End of voltage deviation above the permissible level
7	"Beginning $I \geq I_{OL}$"	Beginning of overload current
8	"End $I \geq I_{OL}$"	End of overload current
9	"Beginning $I \geq I_{SCT}$"	Beginning of short circuit current
10	"End $I \geq I_{SCT}$"	End of short circuit current
11	"$\delta U_{(-)} \geq 95$ % after $I \geq I_{OL}$"	Power supply outage after registering the overload current
12	"$S_{(VPS)} = 0$ after $I \geq I_{OL}$"	Disconnecting the switching device supplying an internal network after registering the overload current
13	"$\delta U_{(-)} \geq 95$ % after $I \geq I_{SCT}$"	Power supply outage after registering the short-circuit current
14	"$S_{(VPS)} = 0$ after $I \geq I_{OL}$"	Disconnecting the switching device supplying an internal network after registering the short-circuit current

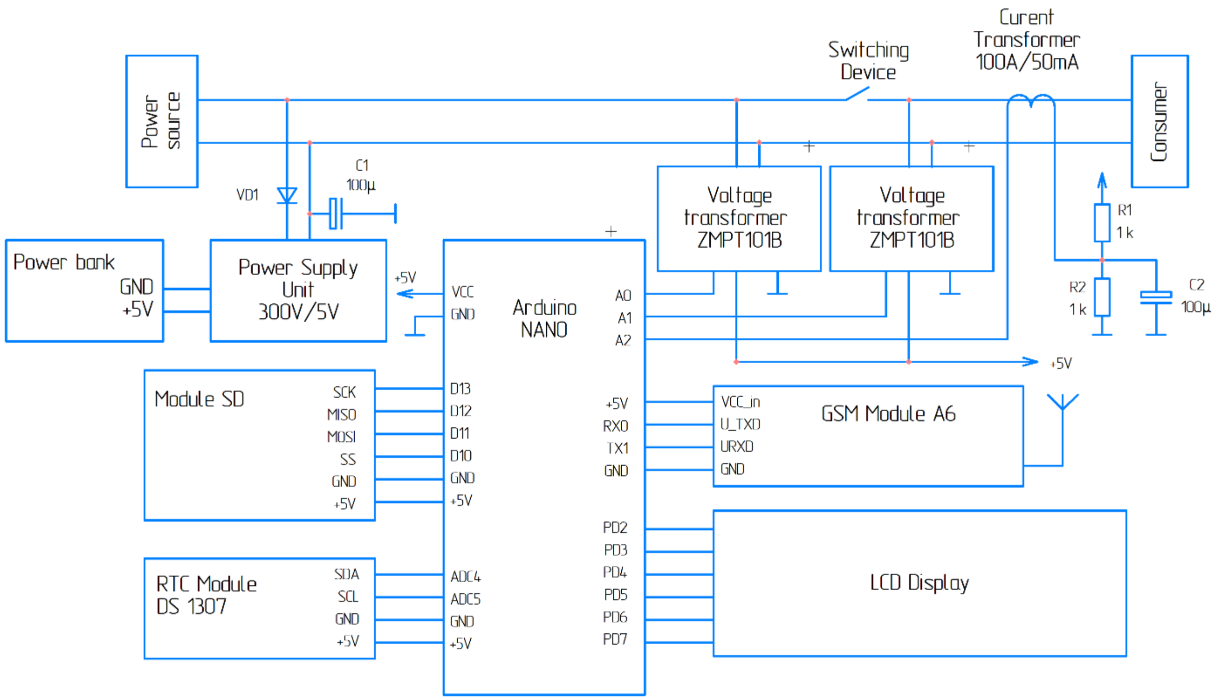

FIGURE 9. Circuit diagram of a prototype of DMPO&VD with GSM data transfer technology.

proceed with the block 43 (Fig. 7), which starts counting the short circuit current. If the overload current does not lead to a short circuit, the algorithm will be looped until the overload is eliminated. It can be caused by three reasons: removal of the overload cause, disconnection of the switching device supplying the consumer and non-selective disconnection of the switching device supplying the power line. Further, the algorithm works as well as detecting short-circuit current. The block 68 will complete counting the overload time, the block 69 will register this fact, and the block 70 will send this information to the DEC.

Further three options are possible. First, the presence of voltage in the external network (blocks 71 and 72) is checked, then the presence of voltage in the internal network is checked (blocks 75 and 76). If the conditions are not met, the algorithm considers that the system is in working condition and returns to the block 3 (Fig. 4) for the new cycle.

Thus, the developed algorithm of DMPO&VD allows accurately detecting all the main emergency modes, registering the fact and the period of their appearance and sending signals about this to the dispatching office of an electrical grid company. The signals from DMPO&VDs allow the DEC to identify the causes of emergency modes of the electrical network, for example, by receiving the signal about power supply outage (non-selective triggering of the switching device supplying a power line) occurred due to a short circuit in the consumer's internal network. The signals which can be sent by DMPO&VD are presented in Table 1.

It should be noted that the algorithm of the device for monitoring the number and duration of power supply outages and voltage deviations installed at the consumer input will be identical to the algorithms of DMPO&VDs installed at the LV buses of a transformer substation and at power lines.

V. RESULTS, DISCUSSION AND FUTURE DIRECTIONS

A. RESULTS AND DISCUSSION

To test the developed structure of the device for monitoring electrical parameters at both sides of a switching device and the operation algorithm of such devices, the prototype of DMPO&VD based on the Arduino microcontroller and using GSM communication as a data transfer technology was assembled. The use of these microcontrollers allows creating prototypes of open-source electronic devices based on flexible, easy-to-use hardware and software [40]. The circuit diagram of the prototype is shown in Fig. 9.

The selected components for the prototype DMPO&VD are:

1) Controller ARDUINO NANO V3 ATmega 328;
2) Current sensor SCT-013-000;
3) Voltage sensors ZMPT101B;
4) LCD Display 1602;
5) RTC (Real Time Clock) DS1307 module;
6) Micro SD card module and Micro SD card 16 Gb;
7) Rechargeable lithium battery NCR18650B 3.7V 3400mAh;
8) GPRS A6 module SIM900A

The assembled prototype of DMPO&VD using GSM communication as a data transfer technology is presented in Fig. 10. The costs of the prototype component parts amounted to 2 808 Russian rubles. It is less than 50$.

Laboratory tests of the prototype of DMPO&VD were conducted. To do this, the device was installed at a stand for modeling 0.38 kV electrical network [41] and calibrated

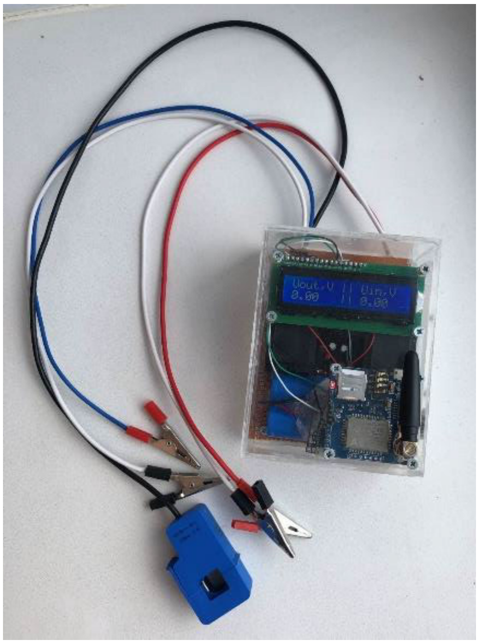

FIGURE 10. Prototype of DMPO&VD.

to current and voltage values by the power quality analyzer ''Resurs UF2M'' as a control device. After calibration and setup of the device the following modes were simulated:

1) Disconnection of external power, i.e. the disappearance of voltage at the power line, with different durations;
2) Disconnecting a circuit breaker from short circuit currents;
3) Disconnecting a circuit breaker from overload currents;
4) Manual disconnecting a circuit breaker;
5) Voltage deviation in a power line by more than 5 % upwards;
6) Voltage deviation in a power line by more than 5 % downwards.

All tests were successful, the DMPO&VD prototype registered emergency modes and the time of their beginning and end, sent signals in accordance with Table 1. Thus, the tests showed that the proposed structure and operation algorithm of DMPO&VD allow carrying out all functions required for the comprehensive SMR&Q operation.

B. FUTURE RESEARCH DIRECTIONS

To date, the prototype of the device for monitoring the number and duration of power supply outages and voltage deviations is in trial operation at LLC ''Elektrosvet'' (Orel, Russia). The device has been being tested in the real system since December 2019. The main task at this stage is to identify all defects hidden in the developed operation algorithm and, according to them, to improve the device. A further task is to create a production prototype of DMPO&VD based on more advanced microcontrollers, at least of the STM type. Here, all the shortcomings that were identified during the trial operation will be taken into account. Another promising idea is to equip a smart meter with the functions of a device for monitoring electrical parameters at both sides of a switching device by introducing an additional voltage transformer installed in front of an input switching device, and programming it in accordance with the developed operation algorithm.

In parallel with the work of enhancing the technical characteristics of DMPO&VD, the important part of further research is to improve the operation algorithms of the SMR&Q software and to program the SCADA system, which allows SMR&Q to effectively use all DMPO&VDs installed in the electrical network under monitoring.

VI. CONCLUSION

The proposed device for monitoring the number and duration of power supply outages and voltage deviations at both sides of a switching device is the main structural element of SMR&Q. Thanks to the upgraded structure and operation algorithm, DMPO&VD is capable of accurately detecting the main emergency modes (voltage deviation below and above the permissible level, overload and short circuit in the internal network, power supply outage in internal and external networks), registering the fact and the duration of their appearance as well as sending this information to the dispatching office of an electrical grid company. Based on this information, SMR&Q allows detecting emergency modes already in the entire electrical network under monitoring as well as their causes.

The prototype of the device for monitoring the number and duration of power supply outages and voltage deviations was assembled on the basis of ARDUINO microcontroller and includes the following components: current sensor, voltage sensors, LCD Display, real time clock module, Micro SD card module, rechargeable lithium battery and GSM module. Laboratory tests of the prototype showed that the proposed structure and operation algorithm of the device allow carrying out all the functions determined for DMPO&VD. Since December 2019 the prototype has been being tested in the real system LLC ''Elektrosvet'' (Orel, Russia).

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