Data acquisition system for capacitive energy storages

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Abstract. Failures in capacitive energy storages result in destruction of faulty elements and other expensive components. Recovery of such failures requires long-term and expensive works to replace and to restore elements of the capacitive energy storage. Diagnostic hardware of the capacitive energy storages makes it possible to limit the consequences of such failures, to reduce the frequency of their occurrence, as well as to monitor the equipment and transmit information on functioning of the pulse current sources to the facility. The operation of data acquisition system in high voltage facilities is accompanied by the electromagnetic interference, and it is therefore necessary to provide the optical fiber transmission lines, the isolation of the diagnostics hardware components and galvanic isolation of their power supply.

1. Introduction
The modern capacitive energy storages are characterized by a high compactness. They are built on capacitors and inductors with a high-energy density and on semiconductor discharge switches. Failures in such facility result not only in destruction of faulty elements, but also in damage of the other faultless and expensive components. For example, failure (breakdown) of one of the diodes in the assembly of a semiconductor switch terminates in failure of all semiconductors in this assembly and damage of the pulse capacitor that fails to withstand a high breakdown pulse current. Besides, other elements of the capacitive energy storage, which will become exposed to electrodynamic forces, electric arc and shock-wave pressure arising during breakdown, will be destroyed. Recovery of such failures requires long-term and expensive works to replace and to restore elements of the capacitive energy storage. Data acquisition system of the capacitive energy storages makes it possible to limit the consequences of such failures, to reduce the frequency of their occurrence, as well as to monitor the equipment and transmit information on functioning of the pulse current sources to the facility controller. The paper presents the results of development and study of such data acquisition system.

2. Operation features of data acquisition system
Pulse discharge of the capacitive energy storage is accompanied by events making difficult operation of the control means and diagnostics:
• high level of electromagnetic radiation (noises), which might introduce perturbation into the electric circuits;
• probable high potential between the common point of the power circuit and the grounding points of the monitoring equipment and controllers;
• input circuits of some diagnostic hardware are connected to the conductors under a high potential.

In view of the above, the following main requirements are imposed on the data acquisition system:
• galvanic coupling between the input circuits of the diagnostic hardware and the monitoring and control apparatus is impermissible;
• the information exchange between the sensors (detectors) and the monitoring and control apparatus should be only via fiber-optical cables. In this case, power of a light signal should be high enough so that possible defects of the optical contacts and the noises in the input circuits of a light signal receiver do not affect the reliability of diagnostic information transfer;
• the diagnostic units located on the high voltage platform are powered by the “current loop” scheme through a high-frequency transformer, which ensures the galvanic coupling and the insulation.

3. Data acquisition system

Data acquisition system provide the operation conditions of the sensors, as well as the conversion of output signals of the sensors and detectors and their transmission to the controller. Data acquisition system comprises the following support systems:
• data acquisition system intended for ADC conversion of output signals of the sensors and detectors and their transmission to the controller;
• current loop power supply ensuring power supply of the transmitters located on the high voltage platforms of the facilities.

3.1. Data acquisition system

The system is intended for acquisition and processing of information received from the sources of analog and logical signals in the control and diagnostic systems of high-voltage pulse facilities. The system comprises signal transmitters and receivers interconnected by fiber-optic cables (figure 1).

![Figure 1. Data acquisition system.](image-url)
The transmitters (tables 1, 2 and figures 2, 3) are located on the high voltage platform of the power equipment. The input analog or logical signals are converted to a sequential code, which is further transmitted to the receiver via the fiber-optic cables. One receiver receives signals from up to 8 transmitters. The receiver (table 3, figure 4) converts the coded signals arriving from the transmitters to the communication messages, which are transmitted to the controller via the Profinet or Profibus Network.

**Table 1. Technical characteristics of voltage transmitters.**

| Characteristics                      | Values                        |
|--------------------------------------|-------------------------------|
| Ranges of normalized input voltages  | ±10 V; 0÷10V; 0÷1 V           |
| Measurement error, no more than      | 1%                            |
| Power supply                         | 18 – 36 VDC                   |
| Overall dimensions                   | 113,2×54×30 mm                |
| Weight                               | 0,12 kg                       |

**Figure 2.** The block diagram of the voltage transmitter, ADC – the analog-to-digital converter, PCM – the pulse code modulator.

In the voltage transmitter the normalized input voltage is divided at the input divider. Then, the scaling amplifier shifts and amplifies the signal bringing it to the input range of ±2.5 V of the analog-to-digital converter (ADC). The ADC converts voltage to a binary digital sequential code. This code is applied from the ADC output to the converter, where it is converted to a self-synchronizing signal with a pulse-code modulation. Then, the electrical signal is converted to the optical one and transmitted to the receiver via the fiber optic cable.

**Table 2. Technical characteristics of the logical signal transmitter.**

| Type of input logical signals | Continuous pulsed             |
|-------------------------------|-------------------------------|
| Power supply                  | 18 – 36 VDC                   |
| Overall dimensions            | 148×104×50 mm                 |
| Weight                        | 0.96 kg                       |

**Figure 3.** The block diagram of the logical signal transmitter.

The logical signal transmitter is made as a set of monostable trigger circuits, one per input channel. The monostable trigger circuit consists of a pre-set decrement pulse counter, counter control circuit and comparator with a memory element. The monostable trigger circuit is triggered by the logical signal edge. When in operation, the monostable trigger circuit output is set to the logical “1”, if the signal frequency at the input is higher than or equal to 30 Hz. If frequency of the input signal is less than 30
Hz, the monostable trigger circuit output is set to “0”. The parallel-to-sequential code converter combines all output signals from the monostable trigger circuit. Then the signals are converted to a self-synchronizing signal with a pulse-code modulation. Thereafter, the electrical signal is converted to the optical one and transmitted to the receiver via the fiber-optical communication line.

**Table 3.** Technical characteristics of the receiver.

| Parameter                                      | Value                  |
|------------------------------------------------|------------------------|
| Sampling period for writing to buffer          | 20 µs                  |
| Depth of write buffer of one channel          | 50000 readings         |
| Resolution of analog-to-digital conversion    | 8 bits                 |
| Power supply                                  | 18 – 36 VDC            |
| Overall dimensions                            | 175x107,2x66 mm        |
| Weight                                        | 0.72 kg                |

**Figure 4.** The block diagram of the receiver.

The receiver operates as follows. A signal from a remote transmitter arrives via the fiber-optical cable at the optical receiver, where it is converted to an electrical signal. Then, this signal with a pulse-code modulation is converted to a parallel code. This code arrives at two units, namely, comparator and ring buffer. The peripheral controller can write the threshold values to the comparator circuit via the multiplexer through the ProfiNet interface. These threshold values are compared with the input signal code. Information on the threshold value excess is available through the interface. The external controller can stop writing to the circular buffer.

### 3.2. «Current loop» power supply

The power supply of the diagnostics in the high voltage circuits is provided by “Current loop” scheme (figure 5).

**Figure 5.** Simplified circuit diagram of the current loop power supply. G – the AC source rated for 5 A, 50 kHz.
Photos of the devices that support the "Current loop" operation are shown in figures 6 and 7. The technical characteristics of these devices are presented in tables 4 and 5.

Figure 6. “Current loop” power supply.

Figure 7. Current loop receiver.

Table 4. Technical characteristics of “Current loop” power supply.

| Parameter                 | Value                  |
|---------------------------|------------------------|
| «Current loop» current    | 5A ±10%                |
| Frequency                 | 50 kHz ±1%             |
| Output power              | 100 VAR                |
| Power supply              | 230 VAC, 50 Hz         |
| Power consumption         | 120 W                  |
| Dimensions                | 200×400×200 mm         |
| Weight                    | 4.8 kg                 |

Table 5. Technical characteristics of “Current loop” receiver.

| Parameter                 | Value                  |
|---------------------------|------------------------|
| Output voltage            | 24 VDC ±2%             |
| Maximum output power      | 5 W                    |
| Power supply              | 5 A, 50 kHz            |
| Power consumption         | 6 W                    |
| Dimensions                | 96×62×34 mm            |
| Weight                    | 0.14 kg                |

The current loop AC source is intended for conversion of 230V, 50Hz input voltage to 5A, 50kHz high-frequency alternating current. In this unit the output current sinusoid is synthesized from fragments (8 per period), each of which is provided by the MOSFET bridge inverter keys switched on in the regime of pulse-width modulation. Current at the unit output is stabilized. The value of this current does not depend on the number of connected current loop receivers and inductance of the current loop circuit within a maximal permissible output power of 100 VAR.

Figure 8. Current loop receiver.
In the current loop receiver (figures 7 and 8), the current of the current loop \( I \) flows through the high-frequency current transformer \( T \). The secondary winding current of this transformer is rectified and smoothed by the capacitor filter Voltage of the capacitor \( C_1 \) is converted by a step-up converter with a parallel switch and is smoothed by the output capacitor \( C_2 \). The receiver is characterized by a high efficiency. Voltage drop in the current loop circuit of the receiver depends mainly on the power transferred to load (\( R_{load} \) in figure 8). The circuit of the current loop and its components is used in high voltage circuits of pulse facility for the sensor power supply and the transmitters.

**Summary**

The presented data acquisition systems have been manufactured. The prototypes of all devices have passed the type tests and have been accepted for use in the high voltage pulse facilities. The use of these devices has made it possible to solve the problems of control over a pulse facility and, in many cases, to avoid failures and destruction of the high-voltage discharge circuits of this facility.

The presented data acquisition system has been used in the development of high-voltage impulse facility (120 kJ, 6 kV) and has proven itself as a reliable and easy-to-use system that provides the solution of a variety of diagnostic tasks, including high-voltage facility of the ITER project.