Algorithm for testing digital substation protection devices in conditions of network distortions in the process bus

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Abstract. The article deals with the digital substation equipment maintenance. Equipping the electrical substations secondary circuits with intelligent electronic devices (IEDs) is an important direction in the electric power industry digital transformation. The purpose of the work is to develop an algorithm for testing digital substation protection devices for the influence of network distortions in the process bus. The tasks are to identify the main distortion types, determine the maintenance content and test it. The need to expand the existing service is determined, the maintenance algorithm is developed and a pilot test of the network distortions effect on the IED protection functions is performed.

1. Introduction
One of the main electric power industry modernization directions is the secondary systems digital transformation of reconstructed and new power plants and substations [1-2]. Measurement, control and protection systems are equipped with intelligent electronic devices (IEDs) based on microprocessor technology instead of electromechanical and electronic relays [3-5]. Integration of the IED into a local area network (LAN) allows achieving a high automation level of secondary circuits [6-7]. An electrical object with a high automation level and the interaction between its elements in accordance with the IEC-61850 standard is called a digital substation [8].
The IEC-61850 standard is focused on networks and communication systems in substations. It describes the rules, formats and protocols for data transmission, defines the requirements for the elements description and the project documentation structure [9].
The IEC-61850 standard allows varying digitalization degrees of substation secondary systems [10].
Currently, examples of digital substations successful construction are known.
Replacement of analog and discrete communication channels between secondary circuit elements with network interfaces has exacerbated the operation and diagnostics problem of protection and automation devices. The digital substations equipment has an advanced control and monitoring system. This allows in the future to carry out condition-based maintenance for this devices instead of planned recovery [11]. However, the existing system for checking protection devices does not take into account the operation features of the digital substation equipment.
The issues of checking the network distortions influence on the IED protection functions are considered in [12-14]. However, there is currently no unified and standardized algorithm for complex testing of protection devices. In this regard, the development and testing of such an algorithm is a relevant task.
2. Digital substation local area network

During LAN operation, network traffic may be distorted. Distortions such as loss, out-of-sequence, delay, and time shift can occur in a digital substation LAN. Network distortions are caused by impulse noise, routing features, increased network load, insufficient hardware performance, and software errors in network devices.

The digital substation LAN topology is shown in Fig. 1 and includes three levels: process, bay and station levels. Electrical measurements from current and voltage transformers enter the station’s LAN through converters, called merging units (MU). After conversion, the measurements are transmitted on the process bus using the Sampled Values (SV) protocol as a multicast transmission to IED-subscribers. At the bay level, horizontal communication between the IEDs takes place using the GOOSE protocol (Generic Object Oriented Substation Event). At the station level, information exchange with higher-level equipment (for example, SCADA) is carried out using the MMS (Manufacturing Message Specification) protocol [9].

![Figure 1. LAN topology of digital substation.](image)

The exchange of data at the process and bay level must take place in real time at high speed. To reduce delays in data processing on the OSI model layers, the GOOSE and SV packets transmission is carried out on the data link layer. The data link layer interface cannot guarantee that the IED-subscriber has received a packet from the IED-source. For the correct operation of the protection devices, it is necessary to guarantee the GOOSE and SV packets delivery to the IED-subscribers, or block protection in the event of a critical data loss or invalid quality of received packets.

GOOSE messages have a guaranteed delivery mechanism [15]. When the state changes, the IED-source generates a large number of messages with a gradual increase in the time delay between them. SV packets cannot be provided with such a guaranteed delivery mechanism as in GOOSE. For the correct interpretation of the corrupted SV traffic, the subscriber IED pre-processes the received data.

3. Maintenance algorithm
The algorithm block diagram for testing protection devices in case of SV packets network distortions is shown in Fig. 2. To check the IED as part of maintenance, it is necessary to perform the standard operations defined in the normative documentation beforehand.

When testing security devices in a network distortions, an external source is used that can generate traffic in the SV format. Testing is performed in three stages.

At the first stage, SV packets are submitted with emergency mode parameters and a flag of invalid quality. If operating correctly, the IED will block the protection functions.

At the second stage, protection testing is performed with out-of-sequence SV packets. If the IED is working correctly, there will be no measurement distortion, provided that the packet mixing interval does not exceed the buffer size. Otherwise, the device should signal that the received data is incorrect.

At the third stage, SV packet loss protection is tested. When working properly, the IED should recover lost data or signal a fault if recovery is not possible.

If the protection does not work properly during testing, the IED configuration settings must be checked. If the defects are not found or are irreparable, it is required to prepare a conclusion on the incorrect operation of the IED data structure and generate a request to the device manufacturer to update its software.

Data on allowable SV packages distortion may not be available in the IED technical documentation. If this data is available, the test results must be compared with the parameters from the technical documentation. If data are not available, threshold values for different types of network distortions should be experimentally determined and recorded in the test report.

![Figure 2. The algorithm block diagram for testing protection devices.](image-url)
4. Digital substation IED testing
The circuit for testing (Fig. 3) includes an external power supply source, an IED with protection functions, a control station (HMI) and interface cables.

The protection device testing results to receiving SV packets with tags of good and invalid data quality are shown in Fig. 4. Testing the device for operability with out-of-sequence SV packets is shown in Fig. 5, a-d. The SV packets loss influence on the protection functions is shown in Fig. 6, a-d.
Figure 5. IED protection testing with out-of-sequence SV packets

Figure 6. IED protection testing with SV packet losses
When generating SV with good and invalid quality of service tags, in the first case, the current protection (overcurrent) was triggered (Fig). When the quality of service is invalid (Fig. 4), the protection is blocked (blocking) and the alarm is displayed (incorrect SV).

When the order of two adjacent samples is changed (Fig. 5, a), the measurements of the IED do not change. With a random change in the 14 SV packets sequence, there is no measurement distortion (Fig. 5, b). With 15 packets, a periodic measurement error occurs (Fig. 5, c), and when mixing 16 samples, the measurement becomes invalid (Fig. 5, d).

In the mode without losses, in accordance with IEC-61850-9-2LE [16], SV-traffic contains 80 samples per 1 period of the measured value (Fig. 6, a). The every 4th packet loss does not affect the measurement (Fig. 6, b). The every 3rd packet loss changes the graph and reduces the amplitude (Fig. 6, c). The every 2nd packet loss makes the measurement invalid and blocks protection (Fig. 6, d).

5. Conclusion

In the research, an algorithm block diagram for testing the network distortions influence on the IED protection functions for digital substations has been developed and experimental testing of the protection device in case of SV packets distortion in the process bus has been carried out.

When receiving network packets with a tag of invalid quality, the IED worked correctly with the protection function blocking.

If the SV packets is out-of-sequence, the correct IED operation is ensured by mixing up to 14 samples. In accordance with the requirements [16], the delay in data transmission in the process bus should not exceed 3-4 ms. Assuming 80 samples per period, the IED buffer size can range from 12 to 16 samples.

The IED stable operation is ensured when every 4th SV packet is lost. The analysis showed that the IED builds a current graph based on blocks of 4 SV packets. When one packet out of 4 is lost, the IED restores the lost value by analyzing other samples. If more than 2 block values are lost, the values are not restored.do not fit conveniently into the text.

6. References

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