MV bay controller with integrated protection, power quality analysis and extended self-testing functions

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Abstract. Novel methods of active on-line testing of analogue measurement channels and binary inputs and outputs of protection relays are presented. Results of laboratory tests with synchronized test signals are included.

Key words

on-line testing, bay controller, synchronized test signals, analogue measurement channels, e-diagnostics, power quality

1. Introduction

A modern e-diagnostic system for MV electrical distribution grid is based on multifunctional bay controllers with integrated protection and power quality analysis functions and extended active on-line self-diagnostics. The data collected in the controllers may be used for central monitoring of the grid and individual objects connected to the grid over a vast area as well as to locally compensate reactive power and harmonic distortions. Therefore the bay controllers must fulfil highest requirements concerning accurate measurements of time relations among numerous analogue and digital signals. To this end sophisticated methods of signal processing have been employed.

These end units are greatly responsible for the reliability of the whole diagnostic system. Therefore they should be equipped with effective on-line self-testing functionality covering as many of their features as possible. Particular attention should be paid to the analogue input channels, which could not be actively on-line tested so far. A method of such testing is presented in this paper. A concept of a multifunctional bay controller performing all necessary functions needed for its operation as an end unit in an e-diagnostic system for MV electrical distribution grid is also presented. For purposes of exemplification one function of such a controller is described in this digest.

2. Novel system of testing of digital bay controllers

Two main groups of actions are postulated which significantly enhance the scope of testing of digital bay controllers:

- on-line self-testing comprising check sums of important program and data areas (settings, event log, active interlocks, passwords), successive RAM test, battery, operability of measurement channels, accuracy of the analog-to-digital converter, internal voltages. All these actions are carried out to some extent in different controllers present on the market and the new system does not ignore them; a novel proposition is to extend the scope of on-line testing of the analog channels in such a way that whole channels, beginning from the controller input terminals, are actively on-line tested.
- remote automatic testing of bay controllers, which comprises opening of the breaker, its disconnection from the bay (by moving the truck out), checking all digital inputs and outputs (from input to output terminals), checking selected functions of the controller (eg. current, ground fault and voltage protections), making a report, moving the truck back in and closing the breaker.

3. Time relations measurement techniques

The best way to measure time relations between signals is to use constant sampling frequency. But in this case for varying line frequency some errors arise during FFT computations. Therefore another method has been proposed consisting in resampling the signals entirely in the digital domain.

The sampling frequency has been chosen with the aim of simplifying the antialiasing filters that precede the analogue to digital converter. The bandwidth of the signal that has to be accurately reproduced is 2 kHz, so the cut-off frequency of the antialiasing filter should be considerably higher. On the other hand the signal frequency components at half the sampling frequency should be adequately suppressed. Assuming that simple two pole RC antialiasing filter is to be used the sampling frequency should equal at least 16 kHz.

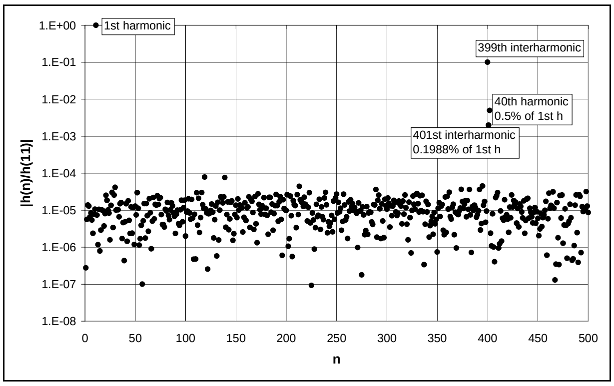

Fig. 1 FFT spectrum of a current waveform with fundamental equal to 53 Hz, after resampling with $N = 600$ and $M = 1769$

At 1024 samples per 10 line periods, the ideal sampling frequency f_{si} is calculated from the equation

$$f_{si} = (f/10)\cdot 1024 = f \cdot 102.4 \qquad (1)$$

where f is the line frequency.

The relative accuracy Er(f), as a function of f, with which f_{seff} approximates f_{si} is equal to

$$\mathrm{Er}(f) = 1 - (f_s/f)\cdot(1/102.4)\cdot(N/M) \qquad (2)$$

The resampling technique resulted in high accuracy of signal spectrum determination which has been illustrated in Fig. 1.

4. On-line self-testing of measurement channels

In order to test complete analog channels on-line, the input terminals included, it is proposed to periodically connect from outside additional test signals of known value (eg. 10-15% of the nominal value) to the input terminals and measure the reaction of the channel under test to the sum of the normal operation signal and of the test signal. If this sum differs from the normal operation signal by the value of the test signal it is assumed that the measuring channel is working correctly. In the opposite case either the channel under test or the testing circuit is defective. Practical implementation of this method of testing requires an external circuit which generates and connects the test signals to the input terminals of the controller (in parallel or in series with the operating signals). The internal software of the controller sequentially gives orders to connect the test signal to a given input, calculates the increase of signal observed at this input, compares it with the known value of the test signal and formulates the result of the test. Additionally, in order to eliminate the influence of the operating signal, changed for the moment of testing, on the normal protection algorithms of the controller, the internal software subtracts the test signal from the measured sum of signals and transfers the operating signal, not modified by the test, to these algorithms. Therefore the testing does not disturb normal operation of the bay controller.

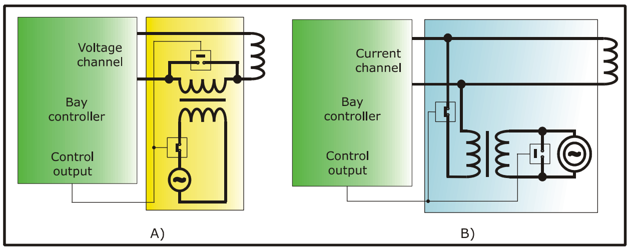

Fig. 2. Simplified diagrams of testing signal driving circuits. A) voltage channel, B) current channel.

The external circuit connecting the test signals to the terminals of the bay controller is composed of two parts. One of them connects test signals to voltage inputs, the other to the current ones. The voltage test signal is connected in series with the operating voltage signal, whereas the current test signal is connected in parallel with the current operating signal. The idea of the test signal connecting circuits is shown in Fig.2 (switches shown in the moment of testing).

It should be emphasized that this method allows for complete active testing of analogue channels without stopping normal operation of the tested bay controller. The method is patent pending.

5. Automatic control of protection relay operability

The above described method of testing analogue measurement channels may be performed during normal operation of the bay controller. In order to check digital inputs and outputs it is necessary to disconnect the controller from the bay. This may only be done after disconnecting the circuit breaker (test position).

Testing of digital inputs and outputs may be carried out after making reconnections in a special test circuit through which, during normal operation, digital outputs and inputs are connected with the bay. This reconnection disconnects the outputs and inputs from the bay and connects the digital outputs with the digital inputs. Then a special test procedure I executed which sequentially changes the states at individual outputs and checks reaction of the inputs to which these outputs are connected. Proper reaction both to the active and non-active states means that both the input and output under test are in good condition. A concept of the circuit for automatic testing of binary outputs and inputs is presented in Fig.3

Completely automatic testing of protection relays is only possible if the distribution bay is equipped with remotely controlled trucks or disconnectors. In such a case the supervisory system may give order to move the truck with the circuit breaker out of the bay to the ‘test’ position or open the disconnectors and then reconnect the inputs and outputs and carry out the test procedure described above.

In the ‘test’ state also other tests may be executed such as testing the ground fault circuit by means of simulation of ground fault current in an additional winding of the Ferranti transformer [5]. Without connecting additional testing apparatuses some protections may also be tested such as U>, U<, I<, U_0> and I_0>. After the tests the normal operation state of the bay may be automatically restored.

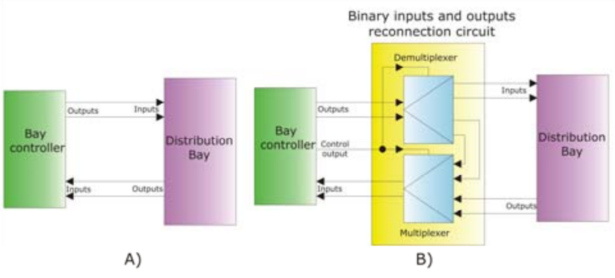

Fig 3. Principle of testing binary outputs and inputs. A) typical connection diagram, B) connection diagram of the binary input and output testing circuit.

The remote supervisory system has direct access to the results of tests. Thus, the actual state of all the protection relays may be monitored, the trends may be analyzed and alerts issued in advance. It may also be helpful in fault situations by ordering additional checks and testing. The level of safety may thus be raised. The IEC 61850 Standard may naturally be used, as it allows supervision of multiple units using common databases and quick interchange of data.

6. Experimental

In order to experimentally check the proposed methods of testing of analogue input channel a model of a test signal switching unit was built. As a device under test a multifunctional protection relay type MUPASZ 7U1, designed at the Tele & Radio Research Institute in Warsaw and widely used in Poland was chosen. For the test purposes its software was modified in such a way that the channel to be tested could be selected by the front panel keys. In the laboratory also a CMC 256 Plus Tester from Omicron was used. Schematic diagram of the test configuration is presented in Fig. 4.

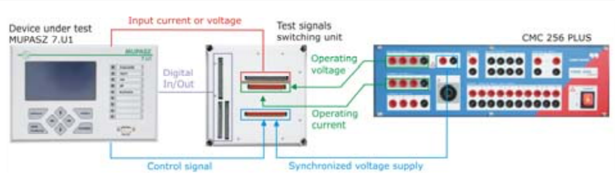

Fig. 4 Analogue channels testing configuration

In the first experiments test signals unsynchronized with the operating signals were used. In this situation the sum of the test signal and of the operating signal has a random value which depends on the momentary phase shift between them (Fig. 5 and 6) and may rather not be useful for testing.

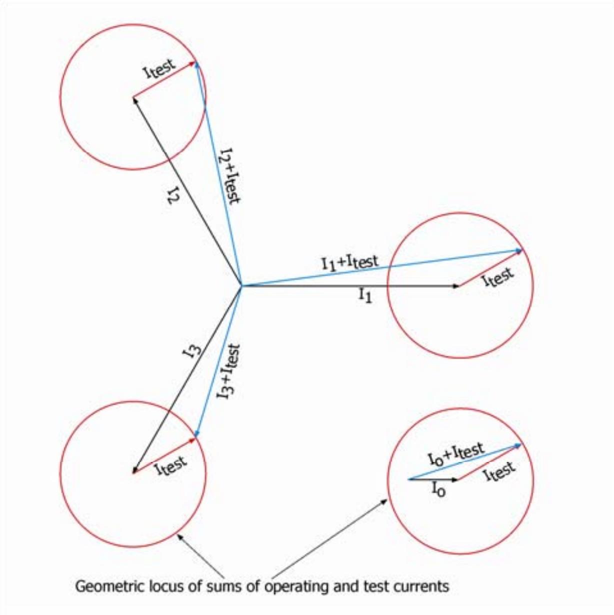

Fig. 5 Current channel testing with unsynchronized test signals

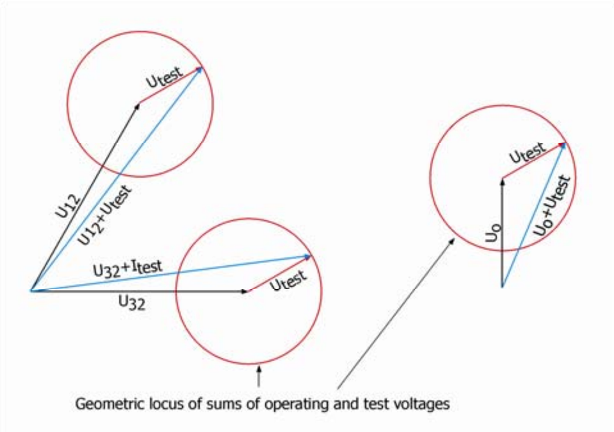

Fig. 6 Current channel testing with unsynchronized test signals

In further experiments the test signal had a determined, though not equal, phase shift versus each phase voltage or current. To this end the test signal switching unit was powered from the voltage channel No. 4 of the CMC 256 Plus Tester and the operating currents and voltages were taken from its relevant current and voltage outputs.

The tests consisted in selecting a channel to be checked (voltage or current), measuring and memorizing the operating value of the signal, sending a signal to the test signal switching unit to generate a known value test signal to be added to the operating signal, making a second measurement and calculating the difference between the second and the first measurement result. If the difference was equal to the known test signal value, the channel under test was qualified as good.

In Table 1 there are collected results of measurements in a defect-free current channel for various phase shifts of the test signal versus the operating signal.

Table 1. Readouts in defect-free current channel; testing signal value 16% of nominal

Phase shift [º]	Measurements [%]		Calculated module of delta [%]	Verdict
	Without testing signal	With testing signal		
0	100	116	16	Pass
180	100	84	16	Pass
120	100	93	16.1	Pass
240	100	93	16.1	Pass
60	100	109	16.2	Pass

Then a defect was simulated in the I1 channel which consisted in lowering the amplification factor of one of the operational amplifiers. Such situation is similar to a partial short circuit on the surface of a PCB caused by a conductive dust deposited after years of operation in a dusty environment. Results of measurements in the defected current channel for various phase shifts are shown in Table 2.

Table 2. Readouts in a defected current channel; testing signal value 16% of nominal

Phase shift [º]	Measurements [%]		Calculated module of delta [%]	Verdict
	Without testing signal	With testing signal		
0	52.5	60	7.5	Fail
180	52.5	44	8.5	Fail
120	52.5	48.9	8.2	Fail
240	52.5	49.1	7.6	Fail
60	52.5	49.3	7.2	Fail

Similar tests were carried out for a defect-free and for a defected voltage channel (U12). The results are collected in Tables 3 and 4.

Table 3. Readouts in defect-free voltage channel; testing signal value 25% of nominal

Phase shift [º]	Measurements [%]		Calculated module of delta [%]	Verdict
	Without testing signal	With testing signal		
0	100	125	25	Pass
180	100	74	26	Pass
120	100	90	25.5	Pass
240	100	90.2	24.5	Pass
60	100	115	25.7	Pass

Table 4. Readouts in defected voltage channel; testing signal value 25% of nominal

Phase shift [º]	Measurements [%]		Calculated module of delta [%]	Verdict
	Without testing signal	With testing signal		
0	44	55	11	Fail
180	44	33	11	Fail
120	44	39.9	10	Fail
240	44	39.3	12.2	Fail
60	44	51	11.9	Fail

7. Conclusion

The methods presented in this paper allow comprehensive on-line testing of bay controllers operating as end units in a wide area e-diagnostics system for MV electrical power grid without affecting their normal operation. Full testing of analogue input channels increases reliability of the bay controllers and of data collected in various points of the grid, which may be used for central monitoring of the grid and of its components as well as to locally compensate reactive power and harmonic distortions. Further work is being carried out to find practically applicable algorithms and solutions for the test signal driving circuits.

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