Paper accepted for presentation at 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania


# Distance protections coordination using the exchange of binary signals in the IEC61850 protocol

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*Abstract*--**The paper presents results of tests investigating the subject of distance protection coordination by exchanging binary signals between substations with IEC61850 protocol. The testing stand, testing methods and devices have also been described. For comparison reasons, the results of the same kind of tests where the SDH network has been used to exchange the information have been described. The paper has arisen on the base of tests performed by Institute of Power Engineering of Warsaw University of Technology on behalf of PSE Operator.**

***Index Terms*-- IEC61850, power system protection, testing of power system protection.**

## I. Nomenclature

PDH - *Plesiochronous Digital Hierarchy*
SDH – *Synchronous Digital Hierarchy*
L90 – *Line differential protection*

## II. Introduction

RECENTLY, there have been more and more discussions and papers on using the computer networks and the IEC 61850 protocol for implementing selected or all systems of the power system protection automatics. The trend of this type is related to the fast development of technologies associated with the computer networks. These technologies, in particular Ethernet, TCP/IP protocols and higher order protocols, including the IEC 61850, allow the proper transmission of large flows of data (e.g. 100Mbps), permitting the development of the fast exchange of data and the construction of power system protections schemes operating with response times in the order of dozen milliseconds. These times are comparable to those obtained in the systems applied to date, which promotes making attempts of using these solutions in practice. Furthermore, due to the possibility of transmitting this type of data also through the wide area network (WAN), this technology becomes suitable for coordination of the operation of the HV/LV lines protections. In the solutions applied to date, very often in such type of control systems, the units called teleprotections have been used for transmitting the binary signals. These units are equipped with the binary input and output modules serving interoperation with the protections and the telecommunication ports allowing data transmission through the direct optical fibre links, PDH/SDH or ETN telecommunication networks.

This paper presents the tests performed in the laboratory of the Power Engineering Automatics of the Power Engineering Institute, Warsaw University of Technology, regarding checking the functional properties of the interoperation of two line protections system inter-exchanging binary signals through the transmission of information in the GOOSE frames of he IEC 61850 protocol, by means of the bridge created in the SDH network channel.

## III. Functional tests of the HV/LV line protections coordination system using the GOOSE mechanism of the IEC 61850 protocol

In the course of tests, the checks of data exchange were made into the data transmitted in the Ethernet standard, in accordance with the IEC 61850 protocol where the SDH equipment is used for constructing the Ethernet bridge linking two local networks, allowing e.g. the transmission of GOOSE messages between the devices installed in various power system substations.

The L90 protections manufactured by GE were used for tests to act as the IEC 61850 compatible equipment, being the multi-function protection units dedicated for HV/LV line protection. Pending tests, the protection function operating signal of one of the relays was used to act as the source of the binary signal subject to transmission.

The protections operated in the telecommunication system as shown in the figure 1. First of them, to which the Relay1-L90 was assigned, interoperated through the Ethernet 10BaseT link with the Ethernet switch manufactured by Ruby, with symbol ES-2126C[1]. The second port of the switch was connected to the Ethernet port of the module with the name Ether-100 of the SDH TN1Ue device manufactured by GE. The second L90 protection, to which the name Relay2-L90 was assigned, was connected directly to the Ethernet port of the second module of Ether-100 operating in the second SDH TN1Ue unit. Both SDH units interoperated through the mono-mode optical fiber links at the wavelength 1300nm. These units exchanged STM-1 frames by means of this link with the

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[1] This is a manageable switch with the following protocols implemented: IEEE 802.3/ab/ad/u/x/z, IEEE 802.1p/q/w/d, 802.1x

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rate 155Mb/s.

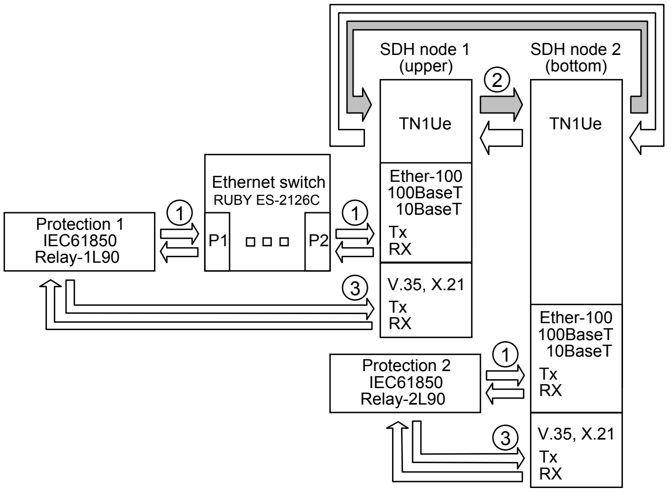


Fig. 1. Block diagram of the telecommunication system in the case of tests of interoperation of the IEC 61850 protections through the Ethernet bridge linking two LAN networks created through two SDH TN1Ue units; 1 – Ethernet link (4 twisted pairs terminated with RJ45 Jack); 2 – optical fibre link (1 pair of single-mode fibres terminated with ST plug); 3 –1300nm optical link converted in external converters into the V.35 (X.21) standard

The CMC156 tester and CMS56 amplifier, generating the total of six current signals and six voltage signals, were used for testing protection devices, involving forcing the relevant values of currents and three phase voltages and checking the response of the protection devices through the analysis of change to the states of binary signals generated by these devices, signaling the triggering. The electrical connections of the CMC56 tester system, CMS amplifier and L90 relays used during tests have been presented in the block form in the figure 2, and in the connections diagram form - in the figure 3. The current and voltage analogue signals from CMC56 tester were connected to the analogue inputs of the first L90 device. The amplifier outputs were connected to the analogue inputs of the second protection device. The output signal from the H2c terminal of the first L90 device was connected to the BI1 binary input of the tester. In order to allow entering binary signals into both protection devices, the first BO1 binary output of the tester was connected to the binary input (H5a terminal) of the first protection device (Relay-1L90), while the second output (BO2) with the binary input (H5a terminal) of the second device (Relay-2L90).

The configuration windows of both L90 devices operation key to the GOOSE proper performance have been presented in the figure 4. The upper part of the figure contains the window defining the content of bits of the vector with the name UserST, sent by the unit with the name Relay 1L90 in the GOOSE message[2] . In this window, the activation signal, with the configuration name of 87L Diff OP, of the differential protection[3] was entered to the second bit of the UserST vector mentioned. It should be highlighted here that, in order to allow the easy check of the response time of the protection systems to the same signal of protection function activation, the same signal was entered into the binary output called Contact Output 2 in the configuration, logically related to the H2 terminals (H2b and H2c) of the Relay-1L90 device.

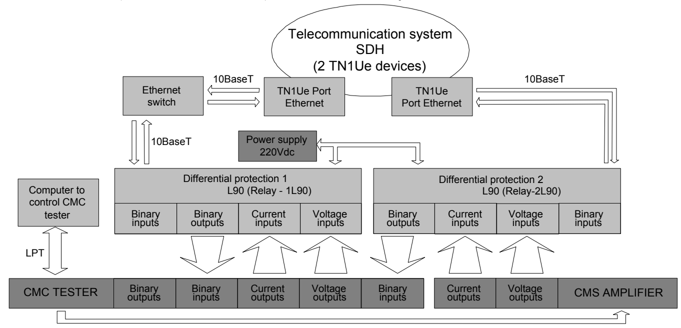


Fig. 2. Block diagram of the L90 and CMC testers system during tests of interoperation of the IEC61850 protections through the Ethernet bridge linking two LAN networks created by two SDH TN1Ue units

As can be seen in the central window presented in the figure 5, in the configuration of the second L90 device with the name Relay-2L90, the state of the second bit of the UserST vector collected in the GOOSE message from the device with the name Relay-1L90 was entered into the variable called REMOTE INPUT 2. In another configuration option, as shown in the window located lowermost in the figure, this same signal, this time called Remote I/P 2 ON (the name defines not only the signal name but also its active status), was provided to the binary output, called in the configuration Contact Output as the H2 – CMC2 logically related to the H2 terminals (H2b and H2c) of the second L90 device.

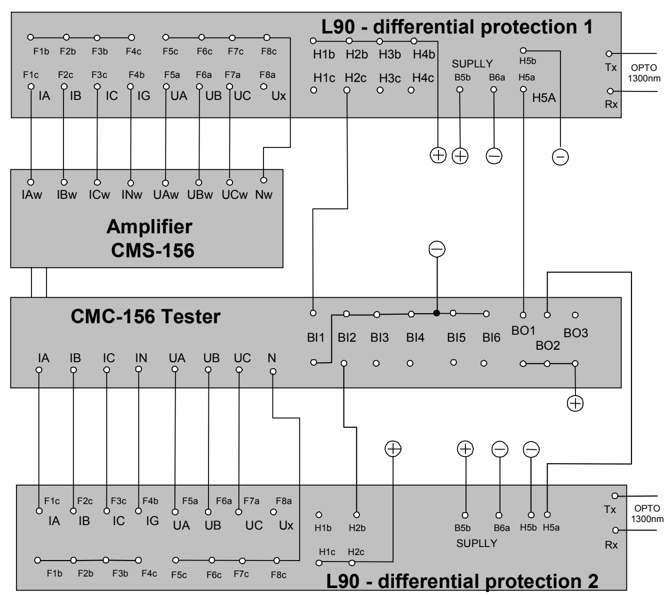


Fig. 3. Connection diagram of L90 devices and CMC testers during tests of interoperation of the IEC61850 protections through the Ethernet bridge linking two LAN networks created by two SDH TN1Ue units

With such configuration, the GOOSE message was broadcast by the Relay1 L90 device at the moment of changing the state of its differential function. The message, as the Ethernet data frame, was transmitted through the Ethernet port of this L90 device to the Ethernet switch, from where it

[2] This type of data frames are called GSSE messages by IEC 61850 standard

[3] The signal assigned to this bit may be any arbitrary signal occurring in the internal logics of the L90 protection, including, e.g. the operation of the first zone of the distance function.

was further transmitted as far as the Ethernet port of the Ether 100 module of the first SDH TN1Ue node. The first SDH node, interoperating with the second one through the optical link, transmitted to it within the STM flow of data also the information accessing the Ethernet port of its Ether-100 module. This information[4] after decoding in the second SDH node, accessed the Ether 100 module of this node, from where it was transmitted to the second L90 device with the name Relay2-L90. This device, following collecting the GOOSE frame, checked the value of the second bit in the UserST vector found in the frame, whose broadcaster was the device with the name Relay-1L90, and transmitted it to the REMOTE INPUT 2 variable, from where it accessed the H2 output, causing its closure.

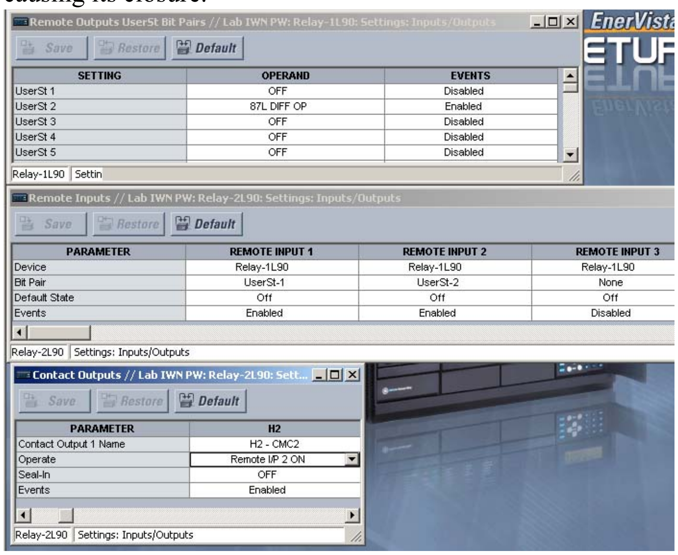

Fig. 4. The appearance of the configuration screen of L90 devices during tests of interoperation of IEC61850 protections through the Ethernet bridge linking two LAN networks, created by two SDH TN1Ue units –GOOSE mechanism configuration in interoperating L90 devices

The tests of devices were completed following achieving the states of proper exchange of data between L90 device. This took place on configuring the equipment and completion of the connections.

Figures 5 and 6 show signals of currents forced and the L90 device behaviour as observed by CMC tester during tests performed in the configuration described. In the upper parts of the figures, there is a table containing the values of times related to the places of positioning of cursors 1 and 2 and the value C2-C1 determining the time that elapsed between them. As can be seen, the left hand cursor is found at the place of the occurrence of the binary signal designated as Trip, showing that the first protection device was triggered. Several milliseconds thereafter, another binary signal appears, designated as Idiff> showing that the second protection was also triggered. First of the black vertical lines located on the left-hand side of the cursor lines mentioned determines the moment when the change to the phase of one of the currents, simulating the occurrence of the internal fault, takes place.

As can be seen from the results presented, the speed of transmitting the information by means of the GOOSE mechanism in the system described amounted to 5ms in the first case and to 82ms in the second case. It should be highlighted here that, with several tests, the results similar to 5ms were much more frequent than those exceeding 50ms (about five times as more). On the other hand, the information acquired from the GE representatives shows that such performance was due to the error in the internal software of the L90 relay, such error being under removal or already removed.

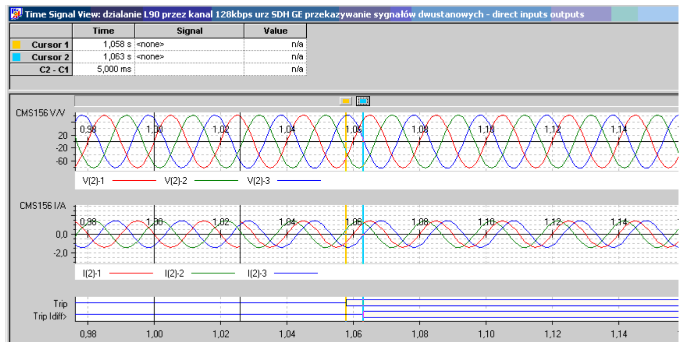

Fig. 5. The results of tests into IEC61850 L90 protections through Ethernet bridge linking two LAN networks, created by two SDH TN1Ue devices with the use of GOOSE mechanism - case 1

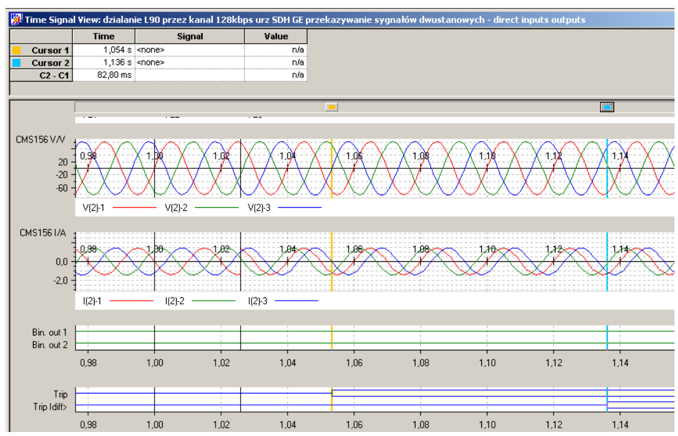

Fig. 6. The results of tests into IEC61850 L90 protections through Ethernet bridge linking two LAN networks, created by two SDH TN1Ue devices with the use of GOOSE mechanism - case 2

It should be highlighted here that, pending testing, also the mechanism of filtration and assigning priorities of Ethernet packages executed by L90 appliances and mechanisms used by Ruby switch and Ether-100 modules of the TN1Ue were checked. It was found out that these devices properly set and interpret the VLAN priority flags. As regards the settings of VLAN IDs, the difficulties were encountered during tests as to the settings of interoperating equipment set such that the GOOSE messages are transmitted properly for the VLAN numbers other than 1. Finding the reasons for such performance is important for the proper operation of Ethernet/IEC 61850 systems in the inter-(sub)station systems, but their detailed and thorough description goes beyond the scope of this publication.

[4] The VC-3 third block was dedicated for Ethernet communication, in accordance with SDH TN1Ue nodes configuration

## IV. RESULTS OF TESTS OF THE HV/LV LINE PROTECTIONS COORDINATION SYSTEM USING DATA TRANSMISSION THROUGH THE OPTICAL LINK AND SDH NETWORK

In order to compare the results obtained with the functional features of the solutions to date, additional tests were performed where the same L90 protection devices exchanged binary signals by means of 1300nm optical link with rate 256kbps. As in previous cases, the source of binary signal subject to transmission was the signal of triggering the current differential function of one of L90 relays. The telecommunication system used during testing has been shown in the block form in the figure 7, while its connection diagram - in the figure 8.

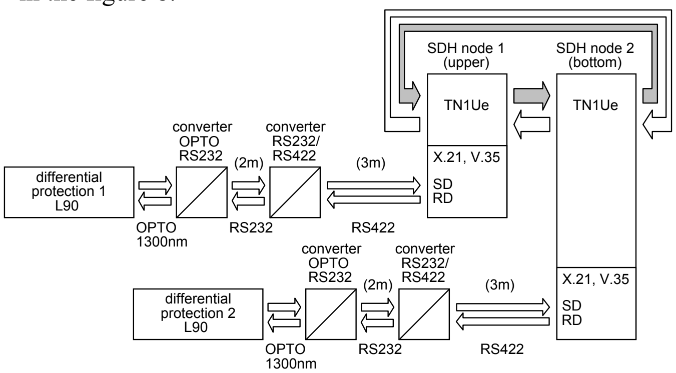


Fig. 7. Block diagram of the telecommunication system in the case of comparative tests into transmission of binary signals from IEC61850TN1Ue devices

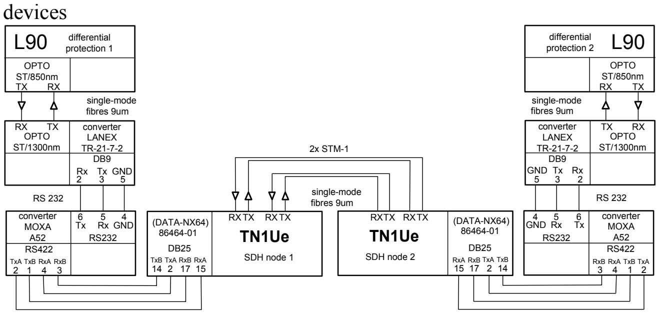


Fig. 8. Connections arrangement between telecommunication ports of devices used during comparative tests of transmitting binary signals from IEC61850 protections

In this configuration, three 1300nm optical signals, following converting in two external converters into X.21 standard, were entered into the same SDH TN1Ue appliances, but this time the DATA-Nx64 (86464-01) modules of V.35 (X.21) standard were used for that purpose.

Figure 9 shows the fragment of the L90 protection devices configuration setting the transmission of the binary signal of the current differential function operation through the optical link mentioned.

As for previous cases, in one of the devices to which the name of Relay 1L90 was assigned, the differential current function activation signal (called 87L Diff OP in the configuration) was provided to the binary output (called Contact Output 2 in the configuration), logically related to H2 terminals (H2b and H2c). The same signal, in the same device, was logically evacuated to the first bit, logically called Direct Output 1-1, located in the bit vector (with the name Direct Output) transmitted in the flow of data sent from this device by means of the optical link. In the configuration of the second L90 device with the name Relay-2L90 the state of the 1-st bit of the bit vector received from the flow of data by means of the optical link is entered into the variable called Direct I/P 1-1. In another configuration option, the same signal this time called Direct I/P 1-1 ON (the name defines not only the signal name but also its active status) was provided to the binary output, called Contact Output in the configuration, as H2 – CMC2 logically related to H2 terminals (H2b and H2c) of the second L90 appliance.

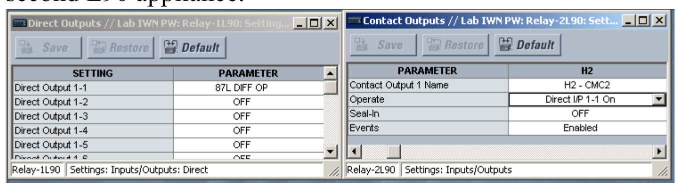


Fig. 9. Appearance of the configuration software screen for L90 devices during comparative tests of IEC 61850 protections - transmission configuration of the binary signal through the optical link of interoperating L90 appliances

Figure 10 shows the signals of the currents forced and the performance of L90 device observed by CMC tester during tests performed in the arrangement described. As in previous cases, the left-hand cursor, designated as C1 is found at the place of the occurrence of the binary signal designated as Trip, showing that the first protection device was triggered, the right-hand one, designated as Idiff> shows the moment of triggering the second protection, while the first of the black, vertical lines located on the left-hand side of the cursors mentioned determines the moment of changing the phase of one of currents, simulating the occurrence of the internal fault.

It should be highlighted here that the system tested was identical[5] to the one currently used in the case of coordination of distance protections operation through the exchange of binary signals by means of telecommunication links, however, it was different from the system where the binary signals are exchanged through the external tele-protection devices. In this second case, the operation response times amounting to 10ms, presented in the figure 10, should be increased by the double conversion time of given signals into the binary signals 220V. These conversions are found in the relay and tele-protection in the course of converting the data signal into the 220V signal and vice versa. As an estimate, it may be adopted that the time lag introduced by the conversion amounts to 8 - 16ms for single transmission direction. Therefore, a conclusion may be drawn that, in the case of operating the system with external tele-protection devices, the response times would be approximately 18-23ms, the value actually encountered in practice.

[5] Identical within the understanding of the principles of data transmission, as, in the systems applied in practice, there are functions or distance protections that are used for sending binary signals, unlike in the tests where the excitement from differential function was used. However, it should be highlighted, as already mentioned, that exciting signal assigned to the bit may be any arbitrary signal occurring in the internal logics of the L90 protection, including, e.g. the operation of the first zone of the distance function.

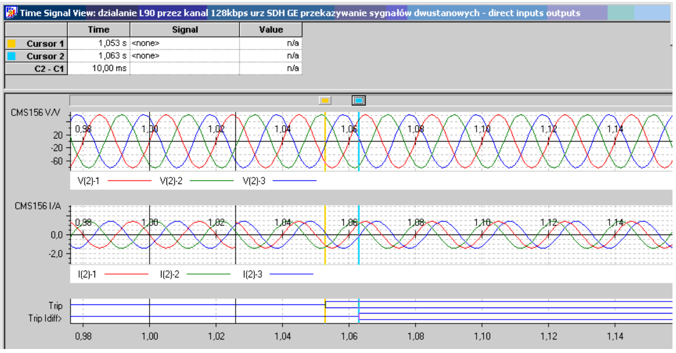


Fig. 10. The results of tests of IEC 61850 protections interoperation through the Ethernet bridge linking two LAN networks, constructed by two SDH TN1Ue devices with use of the GOOSE mechanism

## V. Conclusions from the tests of L90 devices operating in the configuration described

The protection devices performance tests presented checked the possibility of transmitting binary data in the GOOSE message between the protection devices interoperating by means of two Ethernet networks connected by VC-3 flow of data transmitted by SDH network nodes.

The results of tests show that the proper interoperation of protection devices is achievable in such a configuration. The response times observed show that the transmission of data by means of GOOSE mechanism in the configuration mentioned is even twice as fast as in the case of transmitting the data in the dedicated optical link. Unfortunately, currently this coordination method can not be used in practice in L90 devices due to the errors found in these devices in GOOSE mechanism performance, causing that one per few GOOSE messages is delayed by several dozen milliseconds (e.g. 70ms) bringing about the occurrence of the same time lags in transmitting binary signals.

It should be highlighted here that where the external, tele-protection devices are used, their response times achievable would be bigger by some dozen milliseconds, which causes the difference in the response times of teleprotection devices using the GOOSE mechanism as compared to the conventional solutions to be reduced from 100% to 30% (in case the transmission time of GOOSE message will be unchanged amounting to 5ms).

## VI. References

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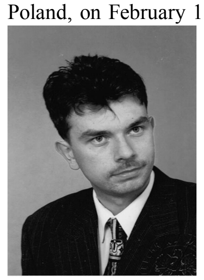
## VII. Biographies

**Ryszard Kowalik** was born in Warsaw in Poland, on September 20, 1965. He graduated from the Warsaw University of Technology in 1989. Since 1989 he has been an employee of the Institute of Power Engineering of Warsaw University of Technology. From 1992 to 1997 he had been working as constructor of microprocessor devices in private company and after 1994 in Polish oil and gas Company. In 1998 he gain his PhD. He is author and coauthor of tenth of scientific research works made mainly for Polish Power Grid regarding the protection, telecommunication and SCADA devices and systems.



**Marcin Januszewski** was born in Łowicz in the Poland, on February 15, 1972. He graduated from the Warsaw University of Technology in 1996. Since 1995 he has been an employee of the Institute of Power Engineering of Warsaw University of Technology. In 2002 he gain his PhD. He is coauthor of tenth of scientific research works made mainly for Polish Power Grid regarding the protection, telecommunication and SCADA devices and systems.