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Analysis of the transmission capacity of various PLC systems working in the same network

***Abstract**. This paper aims to present current knowledge on data transmission between smart grids elements using narrow-band Power Line Communications (PLC) technology. One of the published hypotheses suggests that narrow-band PLC technologies cannot co-occur in the same network without interference. This paper demonstrates the results of laboratory tests for transmission capacity of PLC systems that are made using PRIME and OSGP technologies and work in the same network. The methodology for the interoperability assessment of both PLC technologies is presented with regard to the transmission capacity measurements under reference conditions. On the basis of obtained results practical conclusions were formulated.*

Streszczenie.** W artykule omówiono stan wiedzy na temat transmisji danych pomiędzy elementami inteligentnych sieci elektroenergetycznych (smart grids) realizowanych z użyciem technologii Power Line Communications (PLC) w wydaniu wąskopasmowym. Jedną z hipotez wynikłych z przeglądu literaturowego zagadnienia zawiera domniemanie, że różne wąskopasmowe technologie PLC nie mogą współistnieć w tym samym obwodzie sieci energetycznej, gdyż mogą się wzajemnie zakłócać. W artykule przedstawiono wyniki laboratoryjnych badań efektywności transmisji układów PLC, wykonanych w technologiach PRIME oraz OSGP, pracujących w tym samym obwodzie sieci energetycznej. Przedstawiono metodologię oceny interoperacyjności obu technologii PLC w odniesieniu do pomiarów skuteczności transmisji w warunkach referencyjnych. Na podstawie uzyskanych wyników badań sformułowano odpowiednie wnioski praktyczne. **(Analiza skuteczności transmisji układów PLC wykonanych w różnych technologiach, pracujących w obszarze jednej sieci elektroenergetycznej).

Keywords: smart grids, Power Line Communications (PLC), electromagnetic interference, interoperability, channel capacity.
Słowa kluczowe: inteligentne sieci elektroenergetyczne**,** transmisja danych przewodami elektroenergetycznymi**,** zakłócenia elektromagnetyczne, kompatybilność, pojemność kanału.

Introduction

The last decade brought a global trend for integrating the existing power grids with information and telecommunication networks that are to integrate operations performed by the participants of the production, storage, transfer, distribution and usage processes.

The data transmission between the elements of smart grids may be performed e.g. using various telecommunication protocols, in particular the narrow-band or broad-band (BPL) Power Line Communication technologies (PLC) [1].

The norm EN 50065, i.e. “Signalling on low-voltage installations in the frequency range 3 kHz to 148,5 kHz” regulates four frequency ranged dedicated for PLC transmission (Fig.1) [2,3]:

- A (3-95 kHz) – exclusively for Distribution System Operators (DSO), standard/proprietary protocols,
- B (95-125 kHz) – for end users applications - standard/proprietary protocols,
- C (125-140 kHz) – for data transmition systems, regulated: CSMA/CA required,
- D (140-148,5 kHz) – for alarm and security systems, standard/proprietary protocols.

In the USA and Japan a range of 10 kHz ÷ 490 kHz was dedicated to PLC, whereas in China a range of 3 kHz ÷ 90 kHz.

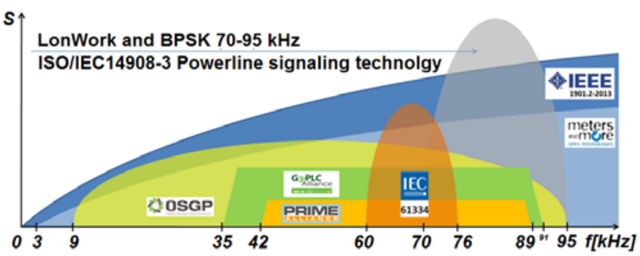

Fig.1. Frequency ranges dedicated for PLC transmission in compliance with EN 50065

Within the range of 3-95 kHz dedicated for PLC transmission for the needs of DSO, a few technologies were created that make use of various overlapping frequency subranges (Fig. 2). Owing to this fact, these technologies are believed not to be able to co-occur in the same network as they might interfere with each other.

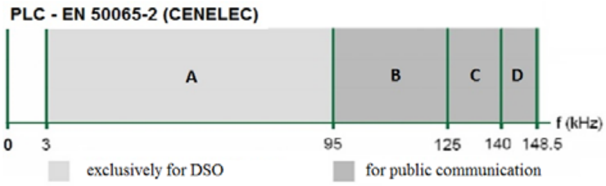

Fig.2. Frequencies in the CENELEC A band are used by various PLC technologies.

The assessment of transmission performance and a possible co-occurrence of various PLC technologies in the same network is complicated by the fact that PLC technology is sensitive to both conductive and induced disturbances [4,5].

This paper presents the results of interference between two PLC technologies: PRIME and OSGP working in the same network separated from the power system.

ICT technologies in power industry

The information and communication technologies (ICT) in modern power industry may be defined as a combination of more and more efficient telecommunication networks (similar to the nervous system), ever-present elements of artificial intelligence (similar to brains), sensors and meters (similar to the sensory system) and software (similar to knowledge and cognitive competence).

Smart metering systems, especially AMI systems (Automated Metering Infrastructure) assure data transmission in both directions between the meter (installed in the energy reception point) and the central management system. From such a perspective, smart metering systems should be regarded as a network of overlapping “nervous” connections between mechanical and energy power sources, building management systems (BMS), transportation systems, embedded systems in household appliances and many systems ensuring users' safety.

Advanced smart metering enable the achievement of the following goals:

- economic: cost reduction and performance enhancement, development of "social power industry",
- technological: safety and power supply quality,
- environmental: sustainable use of natural resources, integration of dispersed energy sources.

In compliance with Directives of the European Parliament and the Council: 2009/72/EC of 13 July 2009 and 2012/27/UE of 25 October 2012 [6,7], the UE Member States carried out long-term cost and benefit analysis of smart metering roll-out on the assumption that by 2020 at least 80% of users will have had the smart metering installed. The results for particular UE Member States are given in Table 1 [8,9].

Tab.1. Results of Cost-Benefit-Analysis of Smart Electricity Roll-Out.

YES	NO	NO DECISION
Austria, Denmark, Estonia, Finland, France, Greece, Spain, Ireland, Luxembourg, Malta, Netherlands, Poland, Romania, Sweden, Italy and the United Kingdom	Belgium, Czech Republic, Lithuania, Latvia*, Germany, Portugal and Slovakia *	Bulgaria, Cyprus, Slovenia and Hungary

*In Latvia and Slovakia the smart metering is considered as economically justified for specific groups of users.

Data transmission between smart grids elements can be performed using TCP-IP protocol (Ethernet), GPRS, LTE, CDMA, while in the HAN zone (Home Area Network) by means of WiFi, ZigBee, RS485, W-Mbus, by the radio (RF) as well as by a combination of two or more of these technologies.

The narrow-band (PLC) or broad-band (BPL) PLC technology (Power Line Communication) is a special implementation of data transmission.

On the basis of the results (demonstrated in Table 1), most countries launched the smart metering programme. Most of the technologies require that the communication channel should be built or the access to the channel purchased (e.g. SIM card), but in the case of PLC we have a "natural" communication channel: the wires of the power grid. That is why, a number of European countries: Sweden, Italy, Ireland, Norway, Finland, France and Spain decided to implement the smart metering systems based on PLC technology.

Power Line Communications in low voltage networks

The use of power grid as a transmission channel has become a focus of numerous researchers [1,10,11,12]. One of the methods of modelling the communication channel is the transfer function (transmittance) that is modelled by two-port chain matrix. In order to establish the function, the propagation constant and wave impedance are used. In PLC application, the impedance of the source must be similar to the load impedance.

The power supply line is a long line with a wavelength corresponding to the frequency of the line voltage and current. A minimum length of wires that can be regarded as long lines can be calculated on the basis of the following equation:

(1) $$l = \frac{\lambda}{4}$$

where: l - length of the line, λ- length of the wave.

The properties of a long line include four parameters:

- Unit resistance R - [Ω/km] related to the energy loss when the energy is changed into heat,
- Unit inductance L - [H/km] related to the magnetic field around the wires,
- Unit capacity C - [F/km] related to the electric field between particular wires,
- Unit leakage conductance G - [S/km] related to the insulation imperfections between particular wires.

Due to the use of two-port network in the line communication model, it is possible to avoid partial equations in the model and take frequency into account. The power supply line is replaced with a series of two-port networks (the scheme of one of them is shown in Fig.3) [13,14].

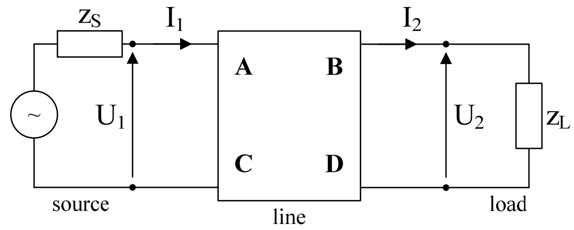

Fig.3. Simplified model of power supply line as a long line

The interdependence of current and voltage in such a line can be demonstrated by the following expression:

(2) $$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix},$$

where parameters A, B, C, D are dependant components in terms of frequency.

This expression may be used to calculate the input impedance and transfer function (transmittance). The input impedance may be expressed as:

(3) $$z_{inl} = \frac{V_1}{I_1},$$

in which:

(4) $$V_1 = AV_2 + BI_2; \quad I_1 = CV_2 + DI_2 .$$

Therefore:

(5) $$z_{in} = \frac{AV_2 + BI_2}{CV_2 + DI_2},$$

(6) $$z_L = \frac{V_2}{I_2},$$

placing (6) to (5) we can obtain:

(7) $$z_{in} = \frac{Az_L + B}{CV_2 + DI_2} .$$

The transfer function (transmittance)

(8) $$H = \frac{V_L}{V_S},$$

(9) $$H = \frac{I_2 z_L}{CI_2 z_L z_S + DI_2 z_S + AI_2 z_L + BI_2},$$

(10) $$H = \frac{z_L}{Az_L + B + Cz_L z_S + Dz_S} .$$

Losses in the transfer function (transmittance):

(11) $$H_{IL} = \frac{z_L + z_S}{z_L} \cdot H\,,$$

(12) $$H_{IL} = \frac{z_L + z_S}{Az_L + B + Cz_L z_S + Dz_S}\,.$$

The ABCD matrix for the transmission line of l length has a wave impedance Z_f and the propagation constant γ as

(13) $$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} ch\gamma \cdot l & z_f ch\gamma \cdot l \\ \frac{1}{z_f} ch\gamma \cdot l & ch\gamma \cdot l \end{bmatrix},$$

where:

- the propagation constant

(14) $$\gamma = \sqrt{(R + j\omega L)\cdot(G + j\omega C)}\,,$$

- the wave impedance

(15) $$z_f = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}\,.$$

The above dependence can be used for modelling physical phenomena (including electromagnetic phenomena) observed in the power line and their impact on the data transmission performance in the communication channel [11,15,16,17,18].

Laboratory tests

In Poland the smart metering systems with PLC technology are implemented by Energa Operator (about 750 thousand meters using PLC technology PRIME) and TAURON Dystrybucja (330 thousand meters using PLC technology OSGP).

Therefore, a model consisting of two three-phase low-voltage networks of about 350 m each was created in the laboratory (Fig. 4); then tests of PLC PRIME and PLC OSGP interference using this model were carried out.

Network A contains data concentrator, two three-phase meters and one one-phase meter using OSGP technology.

Respectively, network B includes data concentrator, two three-phase meters and one one-phase meter using PRIME technology.

In order to determine whether both technologies may co-occur in one low-voltage network, at first the reference conditions of both PLC technologies were separately established with the switch W turned off (Fig.4).

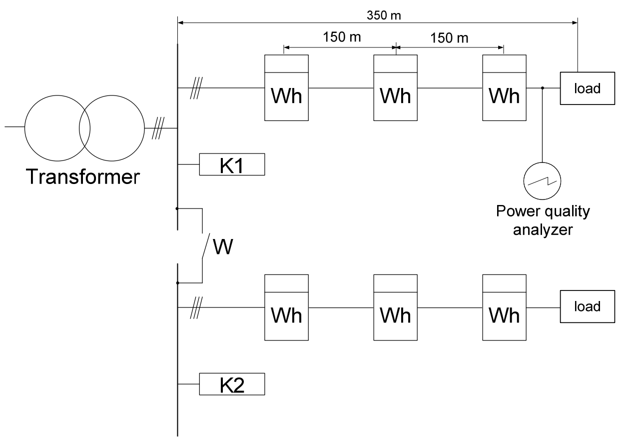

Fig.4. Scheme of the measurement system used in the experiment, where Wh-meter, K1, K2-concentrators

The concentrators and meters were configured in such a way that at an interval of one minute they send 4 energy profiles, the registers status and event log.

The laboratory model was separated from the external power supply system using separation transformers. Due to this solution, the impact of the electromagnetic disturbances caused by the external network was limited.

The following quantitative criteria were accepted for the assessment of the results:

a. the number of logical events that prove the connection stability:

- for PRIME technology: the value of the "SuccessExchanges" parameter reported at a given stage by the application implemented in PRIME concentrator,
- for OSGP technology: the value of the "SUCCESSFULATTEMPTS" parameter reported at a given stage by the application implemented in OSGP concentrator,

b. the number of logical events that prove the connection stability was lost: the meter is unavailable:

- for PRIME technology: the correlated value of the "ERROREXCHANGESSECONDS" parameter reported at a given stage by the application PRIME,
- for OSGP technology: the value of the "FAILEDATTEMPTS" parameter reported at a given stage by the application OSGP

in each of the tests.

c. the transmission capacity – for both technologies the value of the sum of "meter available" and „meter unavailable" divided by "meter available" for a given meter; for each test the value was given as a percentage value.

In Table 2 and in Fig. 5 the values of logical events are presented; the values prove the transmission stability of the PLC technologies under investigation under reference conditions in relation to the measurements made when both technologies were working in the same network at the same time.

In Fig.6 the values of logical events are presented; the values prove the transmission instability of the PLC technologies under investigation under reference conditions in relation to the measurements made when both technologies were working in the same network at the same time.

In Table 3 and in Fig.7 the percentage specification of the transmission capacity is presented for both technologies under investigation under reference conditions in comparison to the measurements made when both technologies were working in the same network.

Tab.2. The results of transmission capacity of PLC technologies under investigation in relation to 1-hour testing

Meter	Number of logical events "meter available" in the reference conditions	Number of logical events "meter unavailable" in the reference conditions	Number of logical events "meter available" when both technologies were working in the same network at the same time	Number of logical events "meter unavailable" when both technologies were working in the same network at the same time
OSGP 2	340	0	328	0
OSGP 3	349	0	343	11
OSGP 4	346	0	329	23
PRIME 2	83	2	43	1
PRIME 3	86	4	43	3
PRIME 4	83	0	44	1

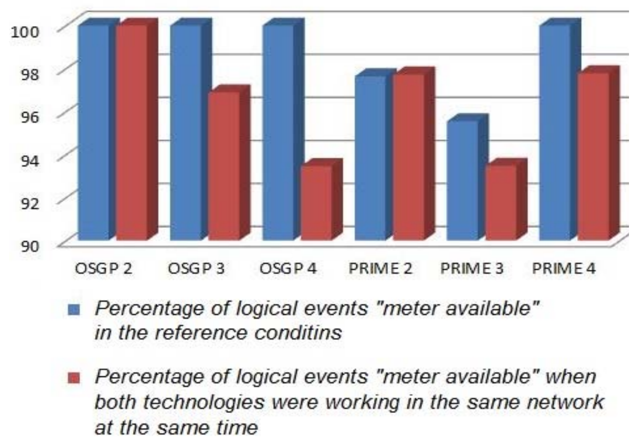

Fig.5. The results obtained for “meter available” in relation to 1-hour testing

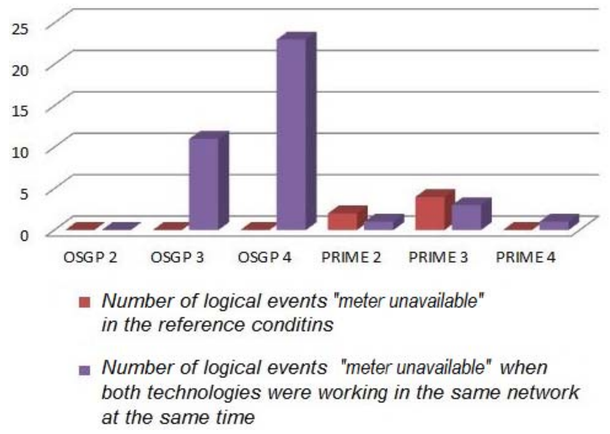

Fig.6. The results obtained for “meter unavailable” in relation to 1-hour testing

Tab.3. Percentage transmission capacity of PLC technologies under investigation

Meter	Percentage transmission capacity in the reference conditions [%]	Percentage transmission capacity when both technologies were working in the same network at the same time [%]
OSGP 2	100	100
OSGP 3	100	96,89
OSGP 4	100	93,47
PRIME 2	97,64	97,73
PRIME 3	95,55	93,48
PRIME 4	100	97,78

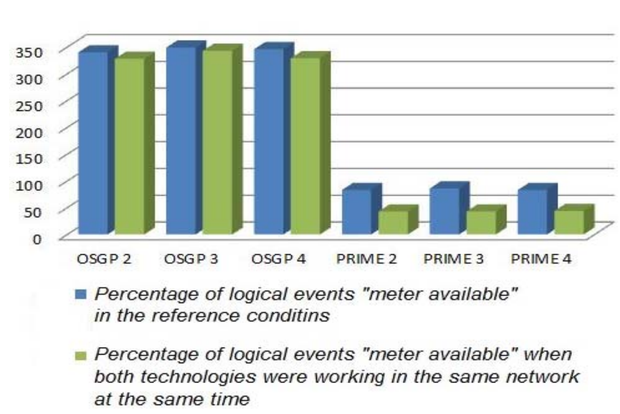

Fig.7. Comparative analysis of percentage transmission capacity of PLC technologies under investigation

The results presented in Tables 2-4 and in Figures 5-7 offer the following conclusions:

1. Simultaneous work of the PLC technologies under investigation in the same power network lowers the data transmission capacity between elements of the PLC system.
2. For OSGP technology, the number of logical events confirming the transmission instability considerably grew as a function of the distance between meters and the concentrator; for the meter installed at a distance of about 2 meters from the concentrator, no transmission errors were detected.
3. The analysis of data concerning OSGP technology demonstrated an exceptionally large number of errors (11 errors for OSGP-2 meter and 23 errors for OSGP-3 meter). At the same time the number of effective meter-concentrator connections doubled; never was so large a number of transmission errors detected in any other experiment carried out by our team (not included in this paper). At all other stages of the experiment, the number of errors ranged from 0 to 2.
4. The analysis of data concerning PRIME technology shows no significant increase in the number of transmission errors in comparison to the reference measurements; the number of effective meter-concentrator connections remained at the same level as under reference conditions.

Conclusions

1. The tests proved that PRIME and OSGP PLC technologies may co-occur in the same power network, though their co-occurrence may lower the data transmission capacity.
2. The algorithms that are implemented in PLC systems and responsible for data transmission capacity increase the number of meter-concentrator connections in the event of transmission disturbances.
3. These algorithms may lead to overloading the communication channel when both PLC technologies work simultaneously in a real network (a few dozens or a few hundred of meters in one system).
4. An effective co-occurrence of both PRIME and OSGP PLC technologies in the same power network requires additional actions taken in order to reduce the risk of overloading the transmission channel with surplus data, which could further result in blocking any meter-concentrator connection, even though those devices were ready for making connections. The required action means that relevant algorithms should be implemented unanimously by the producers of both PLC standards.

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