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Impulse Noise Considerations Related to Data Transmission over High-Voltage Lines

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***Abstract*—This paper describes methods for theoretical modeling of inter-arrival time of impulse noise and presents a new model based on the application of general mathematical distributions, together with its implementation in MATLAB. It also discusses the suitability of this model for development and testing of digital communication systems intended for deployment on high-voltage power distribution lines.**

***Index Terms*—Exponential distribution, noise, probability distribution, simulation.**

I. INTRODUCTION

The PLC (Power Line Communication) systems have been developed many years ago. Their development was focused mainly on communication in power distribution networks and on local data networks in homes.

One of the major problems is the electromagnetic compatibility, as the PLC systems must comply with the radiation limits and, they must be also resistant towards aggressive interference.

The PLC systems are connected to the power lines using inductive or the capacitive coupling elements. Data signal from the PLC system is injected through the coupling element into the power line. The carrier frequency of the data communication is significantly higher than the mains frequency (which is typically 50 Hz or 60 Hz). [1]

II. THE BANDWIDTH OF PLC SYSTEMS

The PLC systems can be classified according to the used bandwidth as the Narrowband power line (NPL) and the Broadband power line (BPL). [1]

A. Narrowband Power Line

The NPL systems have low data rates up to tens of kbit/s and their typical purpose is remote data collection. The NPL bandwidth is defined in the CENELEC specification EN 50065. This specification is divided into three parts [2]:

– EN 50065-1 contains common requirements for the used bandwidth and the electromagnetic disturbance;

– EN 50065-4-2 deals with low-voltage decoupling filters and safety requirements;

– EN 50065-7 deals with impedance of the connected devices.

Table I shows the division of bandwidth in the narrowband power line systems.

TABLE I. OVERVIEW OF FREQUENCY BANDS FOR NARROWBAND PLC [2].

Band	Bandwidth [kHz]	Note
	3–9	Only for the supplier of the power line
A	9–95	Only for the supplier of the power line
B	95–125	Only for private purposes of subscribers
C	125–140	Only for subscribers
D	140–148.5	Only for private purposes of subscribers

B. Broadband Power Line

The frequency bands for BPL systems are not globally standardized and they span from units to tens of MHz. The data transfer speeds are from units of Mbit/s up to Gbit/s.

III. ELECTRICAL NETWORK

The electrical network contains interconnected power stations and power lines for transmission and distribution of electricity. Electrical networks can be divided into the transmission network and the distribution network. The electrical network levels can be classified by voltage [1]:

– Very high voltage: 110 kV, 220 kV, 400 kV and 1000 kV. These electrical lines allow transport of energy over long distances.

– High voltage: 6 kV, 10 kV, 22 kV and 35 kV – transport of energy for cities or industrial areas.

– Low voltage: 230 V, 400 V and 500 V – transport of energy for end-users.

Modelling of power lines is based on the time-dependent telegraph equations. These equations are designed for the elementary segment of a line. The elementary power line segment can be described by the model consisting of passive elements (Fig. 1) [3].

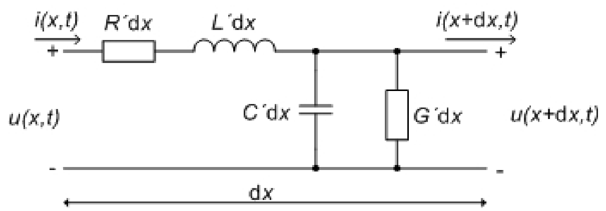

Fig. 1 The elementary power line segment [3].

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The primary parameters *R´dx*, *L´dx*, *C´dx* and *G´dx* describe the properties of the elementary power line segment with length *dx*; they are used in so-called telegraph equations (1) and (2) [3]:

$$\frac{\partial u}{\partial x} + R'i + L'\frac{\partial i}{\partial t} = 0, \quad (1)$$

$$\frac{\partial i}{\partial x} + G'u + C'\frac{\partial u}{\partial t} = 0. \quad (2)$$

IV. INTERFERENCES IN THE TRANSMISSION ENVIRONMENT

There are different kinds of interferences in the transmission environment which negatively affect data transfer in PLC systems. The basic types of interferences are described hereinafter.

A. *Background Noise*

This type of noise is always present in the electrical network because it originates from a large number of noise sources with low intensity and variable in time. The background noise can be described by its power spectral density (PSD) [4].

B. *Narrowband Interference*

This type of interference has typical behaviour – there are narrow peaks with high PSD. At frequencies up to 150 kHz it is mainly due to switching processes, frequency converters, fluorescent lamps, TV sets and computer monitors [4].

C. *Impulse Noise*

The major sources of impulse noise are switching power supplies, thyristor regulators or collector motors. The impulse noise occurs very often in the network power and it is characterized by short voltage peaks with duration from units to hundreds of microseconds, sometimes in units of milliseconds. The PSD of impulse noise is higher than PSD of background noise. Impulse noise can be classified as [4]:

- Periodic synchronous;
- Periodic asynchronous;
- Asynchronous.

V. THEORETICAL MODELLING OF INTER-ARRIVAL TIME

The impulse noise consists of a sequence of impulses arriving at random (or regular – thus deterministic) time instants. Modelling of the inter-arrival time is based on the analysis of impulses.

We performed measurements of impulse noise that originated from electrical appliances and affected the telephone lines. The principle of measuring the impulse disturbance is described in [5]. The inter-arrival time of the measured impulses has been analysed. As a result, it was found that the impulses occurred as a Poisson flow with deterministic distribution, which is shown in Table II.

The Poisson flow and deterministic probability distributions are widely known and used e.g. for modelling of the packets inter-arrival time [6].

The occurrence of the impulses is considered as random events that are independent of each other and have the same probability. The assumption made for modelling of impulses inter-arrival times is the Poisson flow and deterministic probability distribution. It is assumed that the inter-arrival time of the impulses in a PLC system will have the same characteristics as the impulse noise in a telephone line.

TABLE II. OVERVIEW OF THE IMPULSES INTER-ARRIVAL TIME ANALYSIS.

Electrical appliances	**Type of the inter-arrival time**	**Parameter**
Sample I (Blender)	Poisson flow	t_{ia} = 1.24 ms
Sample II (Drill)	Deterministic	t_{ia} = 0.63 ms
Sample III (Dryer)	Deterministic	t_{ia} = 1.02 ms

A. *Poisson Flow*

The elementary probability for the Poisson flow is called the probability of arrival for one (3) or none (4) impulse in the given time interval. This probability is directly proportional to the duration of the time interval a*t* [7]:

$$P_1(\Delta t) = \text{ª}\Delta t + \pm(\Delta t), \quad (3)$$

$$P_0(\Delta t) = 1 - \text{ª}\Delta t + \pm(\Delta t), \quad (4)$$

$$\lim_{\Delta t \to 0} \frac{\pm(\Delta t)}{\Delta t} = 0, \quad (5)$$

where ±(a*t)* is infinitely small value compared with a*t*. ±(a*t)* is so-called Landau symbol [7].

The probability of occurrence of more than one impulse in the given time interval (6) is negligible

$$P_{i>1}(\Delta t) = \pm(\Delta t). \quad (6)$$

The occurrence of *k* impulses during the time interval *(t +* a*t)* is possible only when *k-i* impulses *(0 ≤ i ≤ k)* arrive in the interval *t* and *i* impulses in the interval a*t*. Because the Poisson flow is the flow of independent events (flow without memory, without decay), there are arriving *k-i* impulses during the time interval *t* and *i* impulses during the time interval a*t* interdependently. Therefore applies (7) [7]

$$P_k(t + \Delta t) = P_{k-i}(t) P_i(\Delta t). \quad (7)$$

The equation (8) for the rule of total probability for a complete set of phenomena

$$P_k(t + \Delta t) = \sum_{i=0}^{k} P_{k-i}(t) P_i(\Delta t). \quad (8)$$

The final value for the probability P_i(a*t)* is achieved only for *I = 0* and *I = 1*. The equation (8) can be rewritten for using (3) and (4) in a new equation (9) [7]

$$P_k(t + \Delta t) = (1 - \text{ª}\Delta t) P_k(t) + \text{ª}\Delta t\, P_{k-1}(\Delta t). \quad (9)$$

Then, when a*t* → *0* we will get the following system of differential equations (10) [7]

$$\frac{dP_k(t)}{dt} = -\text{ª}\, P_k(t) + \text{ª}\, P_{k-1}(t). \quad (10)$$

For *k=0*, *k=1* and higher values of *k*, we get the equations (11), (12) and (13):

$$P_0(t) = e^{-\lambda t}, \quad (11)$$

$$P_1(t) = \lambda t e^{-\lambda t}, \quad (12)$$

$$P_k(t) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}, \quad (13)$$

where (13) is the Poisson equation for probability of k impulses arriving in time t. The distribution function (14) for the inter-arrival of successive impulses $F(t)$ is, by definition, equal to the probability that the inter-arrival time of these impulses will be shorter than the time T. This probability is equal to the probability that one or more impulses will arrive within the time interval t. [7]

$$F(t) = P(T < t) = \sum_{k=1}^{\infty} P_k(t) = 1 - P_0(t) = 1 - e^{-\lambda t}. \quad (14)$$

There is the distribution function (14) of the exponential distribution. The probability density (15) for the inter-arrival time of the individual impulses is defined as

$$f(t) = dF(t)/dt = \lambda e^{-\lambda t}. \quad (15)$$

The mean value (EX) and the variance (DX) of the inter-arrival time of impulses are EX(t) = $1/\lambda$ and DX(t) = $1/\lambda^2$.

B. Modelling of the inter-arrival time by the Poisson flow

Modelling of the inter-arrival time with the appropriate probability distribution should use the inverse transformation method that allows transforming of the uniform distribution U uncorrelated (independent) random sequence to uncorrelated (independent) sequence X having distribution function $F_X(x)$. The inverse transformation method is described in [8].

The inter-arrival times of impulses are the Poisson flow with the exponential distribution and the exponential probability density. For modelling these times we used the possibility to transform the uniform distribution, which is defined by the function *rand* on the interval (0,1) in MATLAB, to the exponential distribution by the inverse transform method.

The density distribution function (16)

$$f(t) = \lambda e^{-\lambda t} u(t), \quad (16)$$

where $\lambda > 0$, $u(t)$ is defined as follows

$$u(t) = \begin{cases} 1, & t > 0, \\ 0, & t < 0. \end{cases} \quad (17)$$

The distribution function (18) is then

$$F(t) = \int_0^t \lambda e^{-\lambda x} dx = 1 - e^{-\lambda t}. \quad (18)$$

Equal distribution function of the uniform random variable U:

$$1 - e^{-\lambda t} = U, \quad (19)$$

$$t = -1/\lambda \ln(1 - U). \quad (20)$$

By solving (19) we obtain (20), where $1/\lambda$ is the mean inter-arrival time of impulses, and U is a random variable with uniform distribution.

The inter-arrival time was modelled for the mean value of tia: 1.24 ms. This mean value of the inter-arrival time has been taken from real impulse noise. The source of the real impulse noise is shown in Table II.

Figure 2 shows modelling of the new impulse noise. The new impulse noise has been used with the inter-arrival time of impulses tia = 1.24 ms in the whole interval of 200 ms. The generated impulses in this interval have been generated using the method described in [5]; in this case, the random phase of impulses has been modelled by the exponential distribution. The background noise has been modelled as white Gaussian noise with PSD of -140 dBm/Hz. As seen in Fig. 2, this model reflects considerable noise that can negatively influence data transmission in PLC systems as well as in telephone lines.

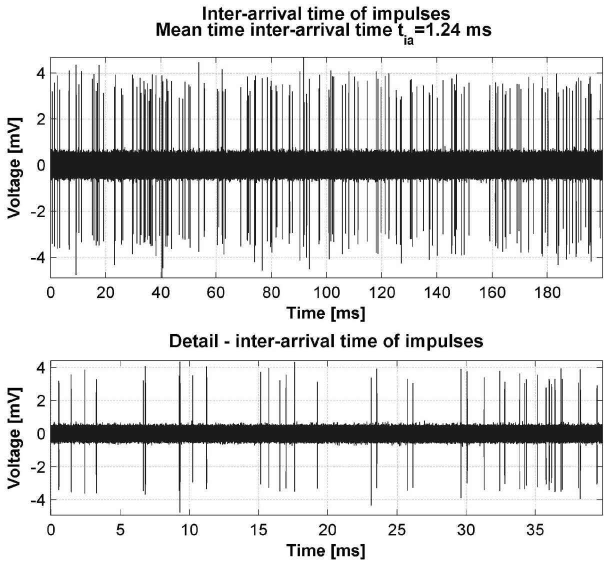

Fig. 2. Poisson flow – Modelling of the inter-arrival time for t_{ia} = 1.24 ms.

This type of modelling could represent the asynchronous impulse noise occurring in the power network.

A. Modelling of the Inter-Arrival Time by Deterministic Distribution

The inter-arrival times of impulses have deterministic distribution in case that the distribution function is:

$$F(t) = \begin{cases} 1, & t \geq t_{ia} = \frac{1}{\lambda}, \\ 0, & t < t_{ia} = \frac{1}{\lambda}, \end{cases} \quad (21)$$

where t_{ia} is the mean value of the inter-arrival time, t_{ia} = EX(t) = $1/\lambda$. The inter-arrival time has been modelled for the mean values of t_{ia}: 0.63 ms and 1.02 ms and for the time interval of 200 ms. This mean value of the inter-arrival time has been taken from real impulse noise. The source of the real impulse noise is shown in Table II.

Figure 3 shows modelling of the new impulse noise with inter-arrival time of impulses with t_{ia} = 0.63 ms in the whole interval of 200 ms. The generated impulses in the whole interval have been generated using the method described in [5]; in this case, random phase of impulses has been modelled by the normal Gaussian distribution. The background noise has been modelled as white Gaussian noise with PSD of -140 dBm/Hz. As seen in Fig. 3, this model also reflects considerable noise.

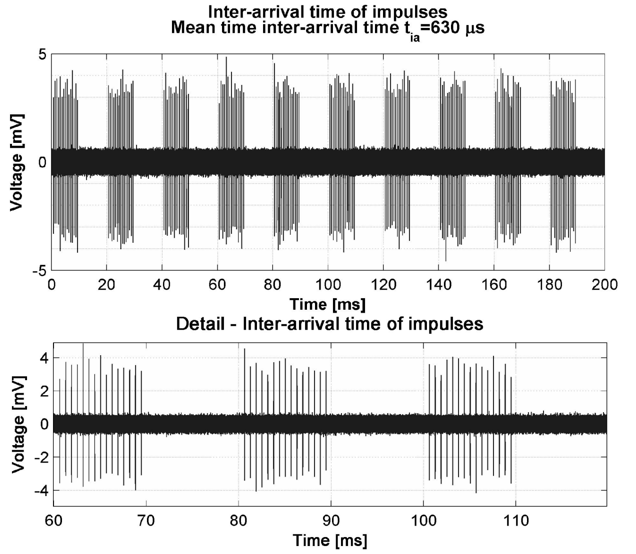

Fig. 3. Deterministic – modelling of the inter-arrival time for t_{ia} = 0.63 ms.

Figure 4 shows modelling of the inter-arrival time of impulses with t_{ia} = 1.02 ms in the whole interval 200 ms.

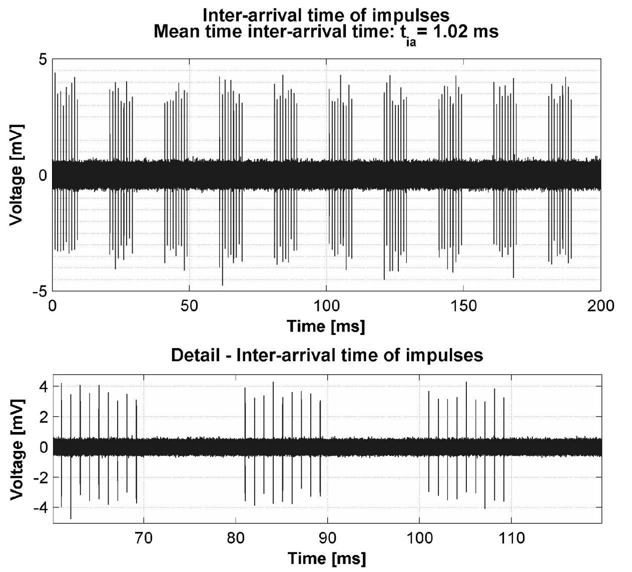

Fig. 4. Deterministic – modelling of the inter-arrival time for t_{ia} = 1.02 ms.

The generated impulses in the whole interval have been generated using same method as the impulse noise above. The background noise has been modelled as white Gaussian noise with PSD of -140 dBm/Hz (same as above). As seen in Fig. 4, this model also reflects considerable noise. As seen in Fig. 3 and Fig. 4, the impulses arrive at the same time according to the inter-arrival time. This type of modelling can represent periodic impulse noise occurring in power distribution networks.

In the first case of modelling can represent the asynchronous impulse noise and in the second case of modelling can represent the periodic impulse noise which occurs in the power network and modelling.

VI. Conclusions

Impulse noise is a type of disturbance that can negatively affect data transmission in telephone lines as well as in PLC systems. This paper has presented modelling of impulses inter-arrival time based on the Poisson flow and the deterministic distribution obtained from real impulse noise in telephone lines.

The results of modelling indicate the capabilities of simulation of impulse noise that can occur in the electrical network as well as in telephone lines. Periodic impulse noise can be simulated using deterministic distribution, as shown in the paper. For this case we used the mean values of the impulses inter-arrival time set to 0.63 ms and 1.02 ms. Asynchronous impulse noise can be simulated using the Poisson flow, as shown in the paper. The mean values of the inter-arrival time have been used, set to 1.24 ms. The model developed in MATLAB will be used to simulate other cases as well, and the model will help us to evaluate the practical knowledge of the interference and its influence.

References

[1] H. Hrasnica, A. Haidine, R. Lehnert, *Broadband powerline communications networks: network design*. Chichester: John Wiley, 2004, p. 290. [Online]. Available: http://dx.doi.org/10.1002/047002092X

[2] *European Committee for Electrotechnical Standardization* CENELEC, 2010. [Online]. Available: http://www.cenelec.eu/

[3] P. Mlynek, M. Koutny, J. Misurec, "Power line cable transfer function for modelling of power line communication systems", *Journal of Electrical Engineering*, vol. 2, pp. 1–4, 2011.

[4] P. Mlynek, J. Misurec, M. Koutny, "Noise modelling for power line communication model", in *35th Int. Conf. Telecommunications and Signal Processing (TSP 2012)*, 2012, pp. 282–286. [Online]. Available: http://dx.doi.org/10.1109/TSP.2012.6256299

[5] J. Krejci, T. Zeman, "Analyses and modeling impulse noise generated by household appliances", *Advances in Electrical and Electronic Engineering*, vol. 12, no. 1, pp. 20–29, 2014. [Online]. Available: http://advances.utc.sk/index.php/AEEE/article/view/942

[6] E. Garsva, N. Paulauskas, G. Grazulevicius, L. Gulbinovic, "Packet inter-arrival time distribution in academic computer network", *Elektronika ir Elektrotechnika*, vol. 20, no. 3, pp. 87–90, 2014. [Online]. Available: http://dx.doi.org/10.5755/j01.eee.20.3.6683

[7] M. Stasiak, S. Hanczewski, M. Glabowski, P. Zwierzykowski, Traffic Engineering in Mobile Networks. *Internationalisation of Electronic Communications Training.*

[8] W. H. Tranter, *Principles of communication systems simulation with wireless applications*. Upper Saddle River: Prentice Hall, 2003, p. 778.