Comparative Study of Impulse Noise Models in the Narrow Band Indoor PLC Environment

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Abstract

In this paper, a comparative study is proposed for two modeling approaches of the random impulse noise measured in narrowband power lines. This study concerns the memoryless Middleton Class A model and the Markov-Middleton model with memory.

Models comparison with measurements is performed and it is shown that Markov-Middleton one is compliant to the impulse noise temporal structure since it considers the pulses samples correlation. However, the comparison in the frequency domain shows that both models do not well represent the frequency behavior of the impulse noise.

Index Terms

impulse noise, Middleton class A model, Markov chains, narrowband plc, stochastic model.

I. INTRODUCTION

Impulse noise has been the subject of a lot of research work, due to its presence in many particular environments, especially the electrical grid. It is considered as one of the most difficult constraint for signal transmission over the narrowband PLC channel because of its random characteristics, permanent presence and high power spectral density that affects communication systems.

In order to define a suitable mitigation technique, the first step is to study its temporal and spectral characteristics then to define a reliable model that could be used in testing the effectiveness of these techniques to cope with signal deterioration.

Different models have been defined and used in literature [1, 3-5, 9, 11], among them the Middleton Class-A model is widely accepted since it is canonical and exhibits a simple probability density function. However, as a memoryless model, it couldn't represent bursts in real impulse noise. That's why the Markov-Middleton model has been defined, basing on Markov chains and taking into account the memory aspect of the noise.

The objective of this paper is to compare these two types of noise models and to study their adequacies to noise characteristics measured experimentally in narrow-band PLC environment.

The paper is organized as follows. In section II, results of the impulse noise measurement campaign are presented. Section III and IV deal with the memoryless Middleton Class A and the Markov-Middleton modeling details, respectively. Models comparison to measurements is discussed in section IV.

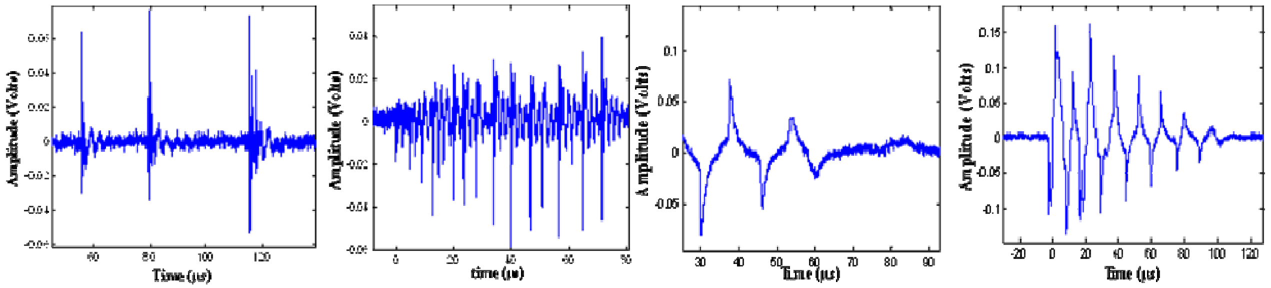
II. NARROW-BAND IMPULSE NOISE MEASUREMENT & CHARACTERIZATION

Experimental measurements of the narrow-band impulse noise have been carried out on the indoor electrical network of several buildings, when activating or deactivating electrical switches, plugging in and unplugging electrical plugs into network outlets as well as when different domestic appliances are in several states (on, off, etc.). A digital oscilloscope connected to a coupling circuit was used to visualize and record pulses from the power line [1-2].

The observation window of recorded noise segments was set to 4 ms, with a sampling rate of 2.5 Mega samples/second.

Pulses temporal shape analysis allowed the identification of four types (Classes) of pulses: a single pulse close to a damped sinusoid (Class 1), a single pulse with exponential form (class 2), a burst that can be considered either as a succession of elementary damped sinusoids (class 3) or a succession of elementary exponential pulses (class 4).

Fig.1 illustrates examples for each class of measured pulses, and Table.1 gives their probability of occurrence among 474 extracted pulses.



(a) Class 1 (b) Class 2 (c) Class 3 (d) Class 4

Fig.1. Examples of measured pulses

Table 1
Pulses Classes repartition

Pulse class	Occurrence probability
Class 1	**43.88%**
Class 2	**24.47%**
Class 3	**12.24%**
Class 4	**19.41%**

From the measurements, it appears that pulses had a mean peak amplitude of 43.3 milliVolts, which shows the low amplitude impulse noise behaviour, and a mean duration of 35.6 µs. It is also noticed that the probability in percentage of having a duration, for class 1 pulses, lower than 10 µs is of 50% and it is increased by 25% for class 2 pulses [13].

III. MIDDLETON MODEL: A NOISE MODEL WITHOUT MEMORY

Middleton Class-A noise model has been extensively used in the literature for modeling impulse non-Gaussian noise from natural and man-made sources [3-5]. It is entirely defined by the three parameters: A, the impulsive index, which represents the density of impulses in one observation period, σ_I^2 which is the variance of the impulse noise and the ratio $\Gamma = \sigma_G^2 / \sigma_I^2$ where σ_G^2 is the variance of the background noise.

The pdf of a noise sample n_k, is given by [5-6]:

$$f_A(n_k) = \sum_{m=0}^{\infty} P_m \, N(n_k, 0, \sigma_m^2) \tag{1}$$

Where $N(n_k, 0, \sigma_m^2)$ is the Gaussian pdf with mean 0 and variance σ_m^2,

$P_m = \dfrac{A^m e^{-A}}{m!}$ And $\sigma_m^2 = \sigma_I^2 \dfrac{m}{A} + \sigma_G^2 = \sigma_G^2 \left(\dfrac{m}{A\Gamma} + 1 \right)$

It was shown that the class A model can be simplified if approximating its pdf by the first few terms of the summation in (1) [7]. That's why in this work, we consider a sum of 5 terms, which gives a normalized pdf as expressed in (2), and a model as illustrated in Fig. 2 [5].

$$f_A(n_k) = \sum_{m=0}^{4} P_m' \, N(n_k, 0, \sigma_m^2) \tag{2}$$

Where $P_m' = \dfrac{P_m}{\sum_{m=0}^{4} P_m}$

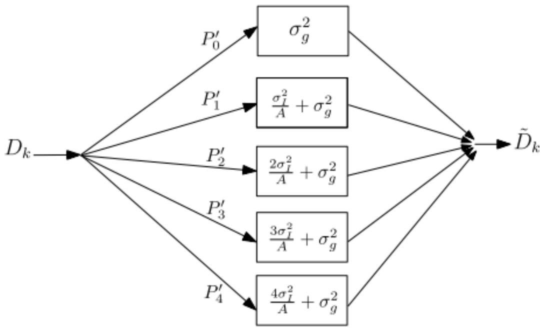


Fig.2. Five-term approximation of the Class A model [5]

In order to totally determine the Middleton Class A model, a statistical study of the pertinent parameters (A , Γ) of the model has been performed, after extracting their values from measured segments. We note that for each measured noise segment of 4 ms, a value of A and Γ is calculated using their definition and the variance of the Gaussian noise component is deduced from its PSD measured on the line when there is no impulse noise.

Results of this analysis, illustrated in Fig. 3 and Fig. 4, prove that the impulsive index A could be approximated to a Gamma distribution, while the cdf of the Gaussian to impulse noise power ratio Γ is well fitted by a log-normal distribution.

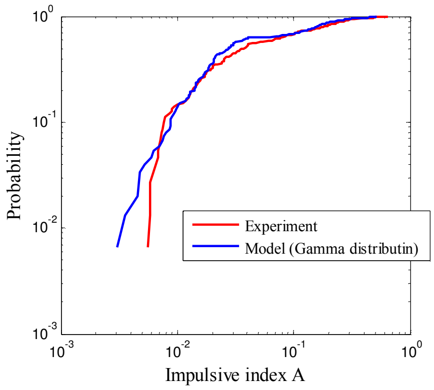


Fig.3. Cumulative Distribution functions of impulsive index A

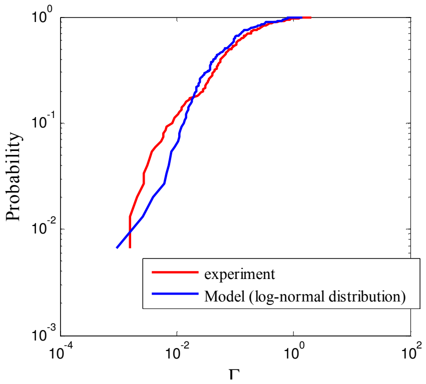


Fig.4. Cumulative Distribution functions of Gaussian to impulse noise power ratio Γ

Table 2

Characteristic values of approximated distribution of Middleton model parameters

Parameter	**Distribution**
A	**Gamma (0.771;01236)**
Γ	**Log-normal (-2.6;15668)**

IV. MARKOV-MIDDLETON MODEL: A NOISE MODEL WITH MEMORY

In order to consider the temporal aspect of the impulse noise and the dependency of its samples that usually occur in burst, many authors proposed models taking into account the channel memory [5,8-9]. Most of them are based on Markov chains theory.

In this work, we focus on the Markov-Middleton model, presented in [5] as a direct modification of the class A Middleton model.

The model is detailed in Fig. 5, with all parameters (A, Γ and $P_i^{'}$) are similar to those of the model of Fig. 2, except the introduction of the memory, using the new probability parameter x. It describes the time correlation between noise samples and could be derived from measurements, as illustrated in expression (3), when considering the impulse mean duration in samples ($\overline{n_I}$) [8].

$$x = 1 - \frac{1}{\overline{n_I} P_0^{'}} \tag{3}$$

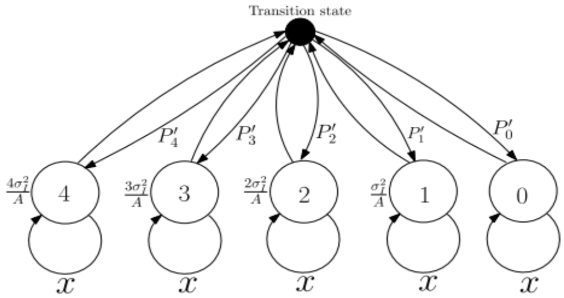


Fig.5. Markov-Middleton impulse noise model with five terms [5]

Fig. 6 gives the complementary cdf of the parameter x, extracted from all measured segments, using expression (3). We can conclude that this cdf can be approximated to a Beta distribution with characteristic values α=76.0509 and β=0.7575.

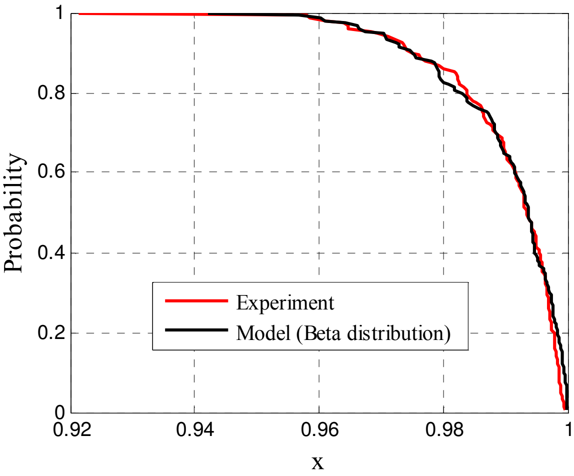
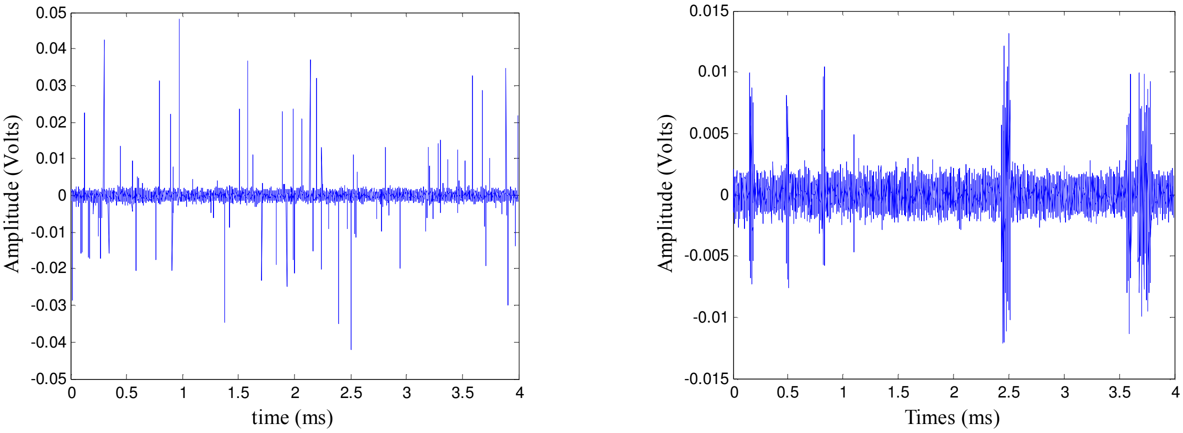


Fig.6.Complementary cumulative distribution function of parameter x

V. MODELS COMPARISON

Once the statistical distributions of different parameters A, Γ and x have been determined, impulse noise on successive observation window of 4 ms was generated following each of the two models previously described.
First comparison deals with time domain aspect showed in fig.7.(a) and Fig.7.(b) for two examples of noise segments generated by Middleton Class A and Markov-Middleton models, respectively.



(a) Middleton Class A model

(b) Markov-Middleton model

Fig.7.Examples of modeled impulse noise

Obtained results show that the impulse memory effect is clearly illustrated in Markov-Middleton model, as opposite to the Middleton Class A, where i.i.d samples are randomly distributed over the entire duration of the observation window.
To verify the compliance of the Markov-Middleton model to the noise temporal structure, we represent in Fig. 8 complementary cdfs of measured pulses duration, in comparison with those generated by the model, and the two curves match, which validate the modeled noise behavior in time domain.

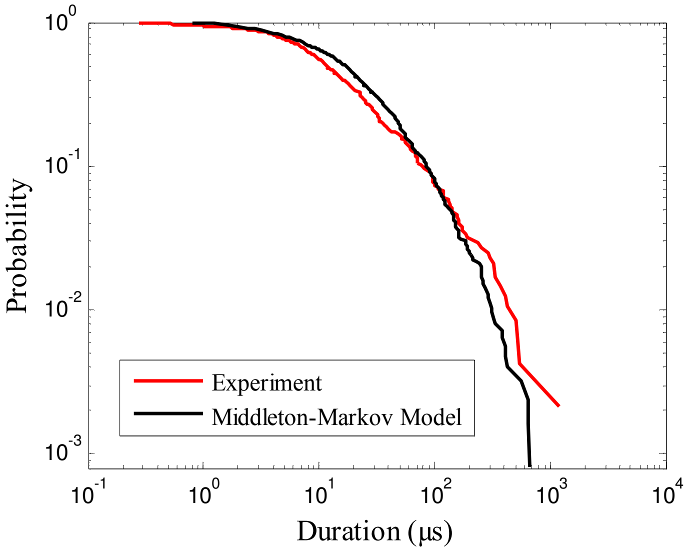
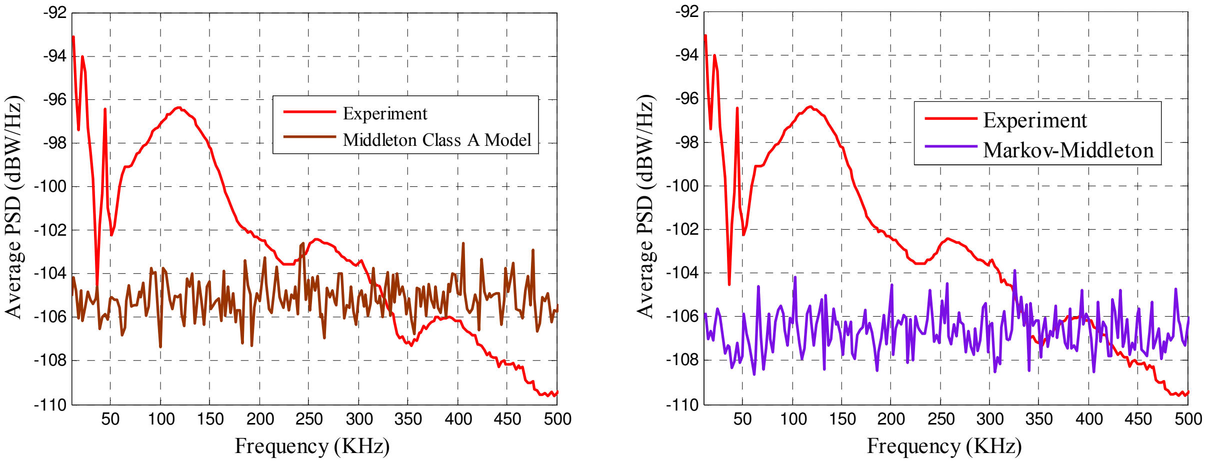


Fig.8. Complementary cumulative distribution of pulses duration

Finally, we compare the two models to measurements, in terms of mean PSD (Power Spectral Density), calculated for each noise segment of 4 ms, in the band [10KHz, 500 KHz].



(a) Middleton Class A model

(b) Markov-Middleton model

Fig.9.Comparison of the models in terms of mean PSD

Fig. 9 shows that the PSD of the two models are similar, and close to a white noise PSD, which is independent of the frequency, as opposite to the PSD deduced from the measured noise. This result can be justified by the fact that in both described models, we do not consider the noise effect in the frequency domain since the frequency is not involved, and there is no pseudo-periodic form of the generated noise.
It is worth noting the existence of the stochastic model [10-11], it takes into account all characteristic parameters of the pulse (pick amplitude, pseudo-frequency, duration & inter-arrival time), and approximate their statistical behavior to well-known distribution functions.

A previous work [12] adopt this model to the Class 1 of the pulses, and when comparing the mean PSD of measured pulses and modeled ones, a good agreement has been noted with a mean residual error less than 6 dB.

VI. CONCLUSION

The paper contribution is the comparison of two impulse noise models and the study of their adequacies to measurements in narrow-band PLC environment. First, we presented main characteristics of narrow-band impulse noise, extracted from the measurements. Then, we detailed two models: the memoryless Middleton Class A and the Markov-Middleton with memory. Statistics of pertinent parameters of each of them were determined and impulse noise was generated following each of the two models.

Comparison of measured and modelled noise in time domain shows that the Markov-Middleton one is more suitable to represent the real noise since the memory effect allows the presence of bursts, as opposite to the Middleton Class A, where i.i.d samples are randomly distributed. However, in frequency domain, PSD curves prove that both models generate white noise with a PSD independent of frequency which is not involved in any of them,

As further work, one can consider a simple transmission schema, and evaluate performances of the link in presence of, first, the measured noise, and then the noise generated by each of the two described model, in order to compare their effects on the transmission.

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