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Denoising Method for Power Line Communication

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Abstract : *The usage of power line as a communication medium is increased recently. Consequently, many researches are conducted in order to assess the system. Noises over the power line communication system are considered serious problem. In this paper many classes of noises are modeled, such as background and switching operation impulse noise over the low voltage level, corona and interference over high voltage level. Extensive analysis is proposed in order to filter these noises. The proposed framework is constituted of some filters, Gaussian, Mean and Median filter.*
Keywords: *Power Line Communication (PLC), Impulsive Noise, Mean Filter, Median Filter.*

I. Introduction

Power Line Communications is the usage of electrical power supply networks for communications purposes. Electrical distribution grids are additionally used as a transmission medium for the transfer of various telecommunications services. The main idea behind PLC is the reduction of cost and expenditure in the realization of new telecommunications networks [1]. Power line communications (PLC) have been attractive as a solution for smart grid communications. We will study the noise types according to voltage levels and frequency ranges.
The electrical supply systems consist of three network levels that can be used as a transmission medium for the realization of PLC networks:

- High-voltage (110–380 kV) networks connect the power stations with large supply regions or big customers.
- Medium-voltage (MV) (10–30 kV) networks supply larger areas, cities and big industrial or commercial customers.
- Low-voltage (230/400 V, in the USA 110 V) networks supply the end users either as individual customers or as single users of a bigger customer [1].

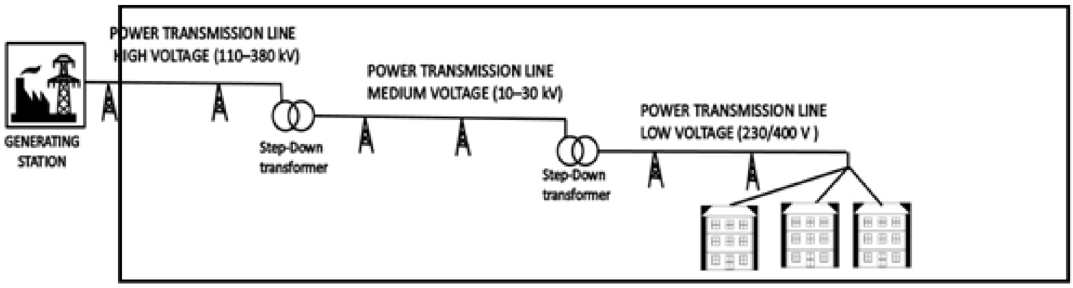

Fig. 1. Power Transmission Lines.

II. Noises Over Power Line Channels

Communication quality is determinedto a high degree by the noise scenarios seen by the receiver. However, thenoise scenario deviates from the traditional AWGN model. It has more complicatedspectral characteristics and features time-varying behavior. The noises are mostly generated by connected electrical appliances or by connection and disconnection of these devices.Typical noise sources are switching power supplies, light dimmers, silicon-controlled rectifiers, brush motors, monitors, and so on. In many appliances, passive elements, such as ferrite cores for noise filtering, are found. Such components can generate or amplify periodic impulsive noise, due to their current-dependent nonlinear characteristics. Many appliances generate noise synchronously with the mains voltage. The resulting noise exhibits periodic features which are synchronized to the mains frequency [4].
PLC noise can be classified as follows:

- Background Noise (Continuous).
  - o Gaussian noise.
  - o Time Variant noise.

- Time Invariant noise.
- Impulsive Noise.
- Periodic
- Random
- Radio Interference.
- Corona Noise

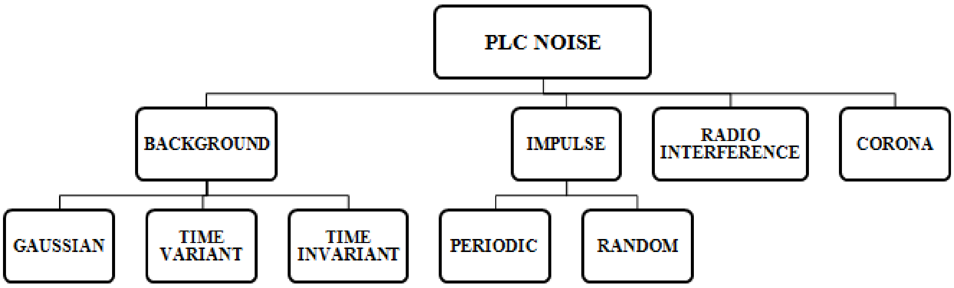

Fig.2. Noise Over PLC Channel.

1. Background (Continuous) Noise

A series of unwanted signals loaded over the original signal, this is caused by the superimposition of numerous noise sources, e.g, computers, dimmers or hair dryers, which can create disturbances. Usually it is characterized by a fairly low power spectral density, whichsignificantly increases towards lower frequencies. In the low frequency range this noise is considered Gaussian with the power spectral density (PSD) [5].
In time domain Background Noise appear in continuous form or in pulses form (narrow band interference).

1.1. Gaussian Noise

This is a random signals having different intensity at different frequencies. It is considered as background noise of many communication systems. The main source of this type is the connection of the network of the system which added to the main signal reducing the system performance, also called Additive White Gaussian Noise (AWGN).

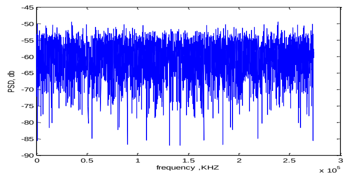

Fig. 3. Power spectral density of Gaussian noise.

1.2. Time-Invariant Continuous Noise

This type of noise has a constant envelope for a long period of time (at least more than a few cycles of mains AC voltage). This noise is also referred to as Background Noise caused by superimposition of many appliances that create disturbances for a long period of time. In low frequency range this type can be modeled by Gaussian model.

1.3. Time-Variant Continuous Noise

This type of noise has an envelope that changes synchronously to the mains absolute voltage. Thus the noise period is half the mains AC cycle duration.
The main sources of this type is as follows:

- The Thermal Noise caused by transmission line and front-end amplifiers of transmitter.
- The system Noise. A typical source for this type of noise is an appliance with an oscillator whose power supply is a rectified but not smoothed voltage. Induction heaters and inverter-driven fluorescent lamps are examples of such appliances [6].

2. Switching operation impulse Noise

The switching operations in power network cause different types of noise. While corona noise have a same behavior over a long time (minutes or hours), the operation of circuit breakers and isolators in the power line networks results in high amplitude impulse noise and duration from milliseconds to few seconds.
Switching operation Noise can be classified as follows:

2.1. Periodic Impulsive Noise

Cyclic impulsive noise synchronous to AC mains is a class of noise waveforms composed of a train of impulses with the frequency of AC mains or double. A typical cause of the noise in this class is a silicon-controlled rectifier or thyristor-based light dimmer. This device controls the brightness of a light by switching the AC current based on its phase, and thus switching noise (impulses) occurs synchronously to the mains voltage. An appliance with a brush motor is another source of this class of noise. In this case, switching at the brushes of a motor is more frequent, and since noise amplitude depends on the AC (absolute) voltage, the impulses show the periodicity of the mains frequency.

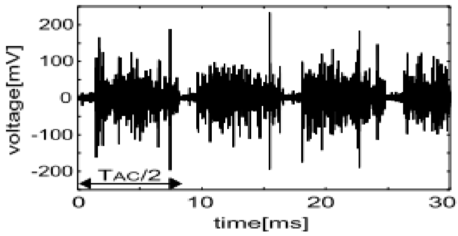

Fig.4. Periodicity of impulses.

Cyclic impulsive noise asynchronous to AC mains is a class of noise waveforms composed of a train of impulses with a frequency much higher than that of mains AC. A typical cause of this class of noise is a switching regulator. The circuit breaker operation for connection and disconnection of transmission line to power network cause a noise of impulse amplitude varying from -10 dBu' up to 25 dBu. These noises have duration from 5 to 20 ms and pulse density from 1000 to 2000 pulses per second [7].

2.2. Random impulsive noise

Isolated impulsive noise is composed of impulses that occur at random timing, often with long (more than seconds) intervals. It has a sporadic nature, mainly due to transients caused by connection and disconnection of electrical devices. This noise is caused when a wall switch or a thermostat in heaters/foot-warmers, for example, makes/breaks the mains AC current. Slow speed isolator operation may occur frequently as normal switching operations inside a power network. This operation generates also high amplitude noise and has long duration of about 0.5 "s" to 5 "s". The duration of noise depends on the isolator design. Detailed look at a part of the impulse caused by isolator operation shows the train of impulses with peak amplitude value in the range from 20 to
390 V [7].

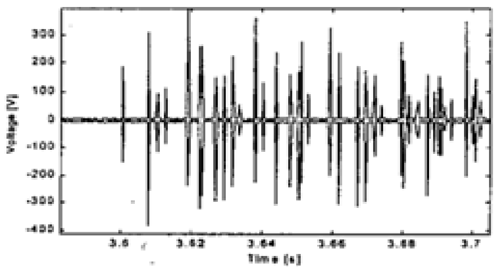

Fig.5. Noise caused by isolator operation.

3. Radio Interference Noise

This type of noise consists of sinusoidal signals with modulated amplitudes. Narrowband noise sources are mainly broadcast radio stations in short, middle, and long wave ranges. This noise can be regarded as ‘interference from wireless to PLC’ and is also called a tone jammer and can be described as

$$n_{nb}(t) = \sum_{k=1}^{N} A_k\,(t)\sin\,(2\pi f_k t + \varphi_k)$$

Where N represents the total number of narrowband interferers, and A_k(t),f_k and $\varphi_k$describe the amplitude, central frequency and phase of the received narrowband noise, respectively. Total number of interferers and their central frequencies can be extractedby empirical measurements and phase φ_k of each noise source can be selected randomlybetween [0; 2π] [7].

4. Corona and Partial Discharge

The ionization of air surrounding the conductor of power line due to electrostatic field of these lines generates corona currents in the form of impulse pulses. Corona discharges, randomly distributed along the high voltage power line, inject current impulses into bundle conductors. Each time when the voltage on a particular phase is high enough a corona burst occurs, and noise is generated.

Although conductors are designed to minimize corona discharge, surface irregularities caused by damage, insects, raindrops or contamination may locally enhance the electric field strength sufficiently for corona discharges to occur.

The corona noise level generated by overhead power lines suffers from various parameters such as [8]:

- Atmospheric conditions
- Line length
- Average value of altitude
- Size of conductors and their configuration
- Type of connection
- Bundle conductor composition
- Voltage gradient
- Ground resistance

The corona-generated currents change with atmospheric and also environmental conditions that cannot be defined accurately and are uncertain in nature. To deal with these generated currents, it is appropriate to represent them with a probabilistic model, which takes into account the uncertainties of the above-mentioned parameters. Apart from atmospheric conditions, which have a predominant influence on the corona noise level and vary with time, there are also some other factors that affect the level of noise PSD, but they are almost constant in any weather conditions and normal operation of the power line.

Because of the nature of the corona noise, the HV power line as a communication channel does not represent an AWGN environment [8].

Noise and voltage levels

The network topology and the appliances affect the channel and introduce a special type of noise in each level channel.

Table: 1 shows some properties of each noise, which voltage level affected with.

Table 1. Noises and voltage levels.

	Noise	**Voltage level**
Continuous Noise	Gaussian	Low and medium
	Time Invariant	Low and medium
	Time Variant	Low and medium
Switching Operation	Periodic	Low and medium
	Random	Low and medium
NB Interference		High voltage level
Corona And Partial Discharge		High voltage level

III. De-Noising Power Line Communication Channel

Gaussian and impulse noise removal

In digital communication systems Gaussian distribution has been widely used as a typical noise source. Besides, AWGN noise, signals that aretransmitted over power cable experience switching impulse noises and various degree of interferences. The mainculprit that slows down the development of PLC for communication is impulsivenoise. The two noise models can adequately represent most noise added to PLC, Gaussian noise (additive) and impulse noise (multiplicative).

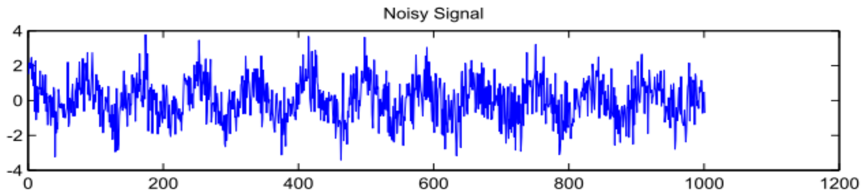

Fig.6. Gaussian noise.

In PLC channel, impulsive noise is more detrimental than AWGN noise. Generally, the impulsive noise in PLC has tail heavier than AWGN noise in its distribution. The impulses are spikes with ideally zero width and infinite amplitude. Impulsive noise is a non-stationary, binary-state sequence of impulses with random amplitudes and random positions of occurrence. The non-stationary nature of impulsive noise can be seen by considering the power spectrum of a noise process with a few impulses per second.

PLC systems, in response to a large-amplitude impulse, exhibit a nonlinear characteristic and may be assumed time invariant. In signal restoration, the objective is to separate the noise from the signal, and the representation domain must be the one that emphasizes the distinguishing features of the signal and the noise. Impulsive noise is normally more distinct and detectable in the time domain than in the frequency domain, and it is appropriate to use time domain signal processing for noise detection and removal.

An impulsive noise sequence can be modelled as an amplitude-modulated binary state sequence, and expressed as

$$ni(m) = n(m) * b(m)$$

Where b (m) is a binary-state random sequence of ones and zeros, and n (m) is a random noise process.

In a Bernoulli-Gaussian model of an impulsive noise process, the random time of occurrence of the impulses is modelled by a binary Bernoulli process b(m) and the amplitude of the impulses is modelled by a Gaussian process n(m) [9].

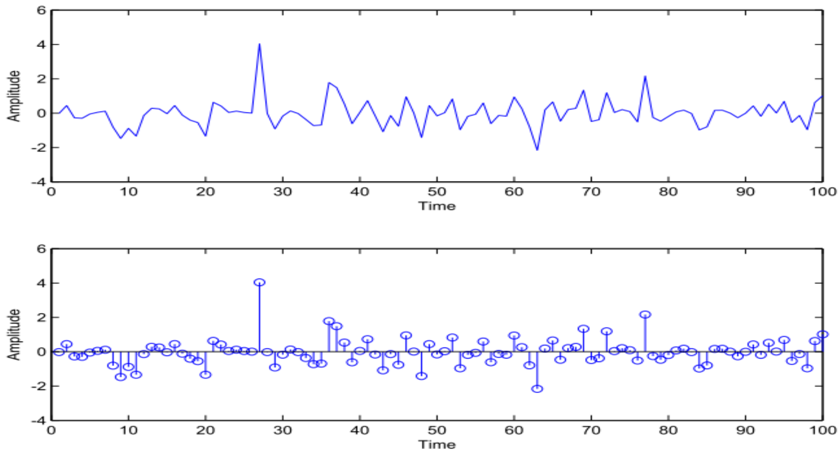

Fig. 7. Impulsive noise using Bernoulli-Gaussian model.

The design of filters used for denoising PLC by means of computer simulation requires detailed discrete model of power line noise. The computer simulation based on channel model provides solution for filtering PLC communication system.In this paper experiments done over noisy signal with 300 MHz with Gaussian and impulse noise.

1. Gaussian filter

However, in several cases one cannot find an acceptable linear filter, either because the noise is non-additive or non-Gaussian. For example, linear filters can remove additive high frequency noise if the signal and the noise do not overlap in the frequency domain. This is the output of Gaussian filter with zero mean and standard deviation =0.5

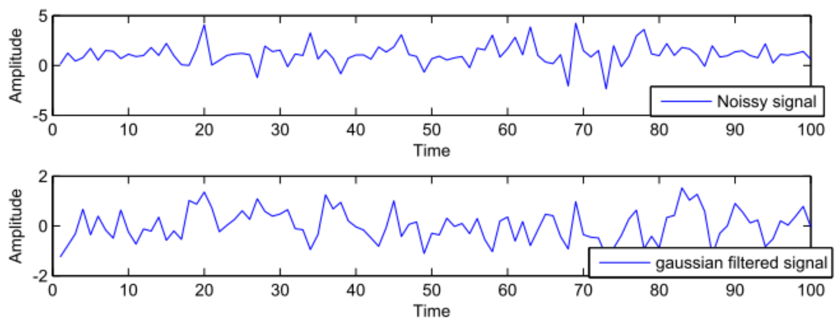

Fig.8. Gaussian Filter Output signal with PSNR=4.5452 dB

In this case a linear low pass filter yield bad results. Nonlinear filters should be used instead.

Nonlinear filters are sometimes used also for removing very short wavelength, but high amplitude features from data. Such a filter can be thought of as a noise spike-rejection filter [10].

2. Mean (Average) Filter

The mean average is the most common filter in DSP, mainly because it is the easiest digital filter to understand and use. In spite of its simplicity, the moving average filter is optimal for a common task: reducing random noise while retaining a sharp step response. This makes it the premier filter for time domain encoded signals. However, the moving average is the worst filter for frequency domain encoded signals, with little ability to separate one band of frequencies from another. Relatives of the moving average filter include the Gaussian, Blackman, and multiple pass average. These have slightly better performance in the frequency domain, at the expense of increased computation time [11].

As the name implies, the moving average filter operates by averaging a number of points from the input signal to produce each point in the output signal. In equation form, this is written:

$$y[i] = \frac{1}{M}\sum_{J=0}^{M-1} X[\mathrm{i}+\mathrm{j}]$$

Where x [ ] is the input signal, y [ ] is the output signal, and M is the number of points in the average.

By applying mean filter to the impulse noise signal the PSNR of the output is 2.7717 dB

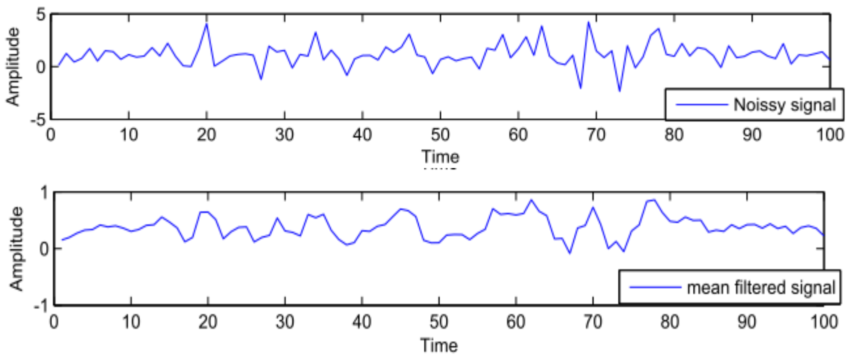

Fig.9. Mean filterOutput signal with PSNR=2.771 dB

3. Median Filter

Median filtering is a non-linear filtering technique that is well known for the ability to remove impulsive-type noise, while preserving sharp edges. The median filter is an order statistics filter. Also Mean filter is used to remove the impulse noise. The classical approach to removal of impulsive noise is the median filter. Hence the median of a set of samples is obtained by sorting the samples in theascending or descending order, and then selecting the mid-value. In median filtering, a window of predetermined length slides sequentially over the signal, and the mid-sample within the window is replaced by the median of all the samples that are inside the window [12].

The output xˆ (m) of a median filter with input y (m) and a median window of length 2K+1 samples is given by:

$$\hat{X}(m) = \mathrm{y}_{\mathrm{med}}(\mathrm{m})$$

$$\hat{X}(m) = median\ [\mathrm{y}(\mathrm{m}+\mathrm{K}), \ldots\ldots, \mathrm{y}(\mathrm{m}), \ldots\ldots \mathrm{y}(\mathrm{m}+\mathrm{K})]$$

The median filter is the best filter to obtain the highest SNR=10.1544

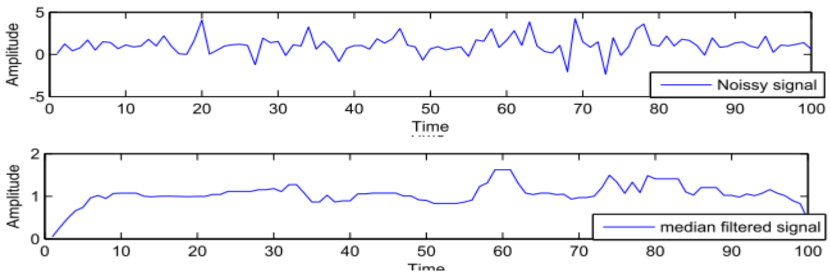

Fig.10. Median filterOutput signal with PSNR=10.1544 dB

Figures: 11, 12 show the Comparison between the Gaussian, mean and median filter explain the difference in time domain and frequency domain using FFT.

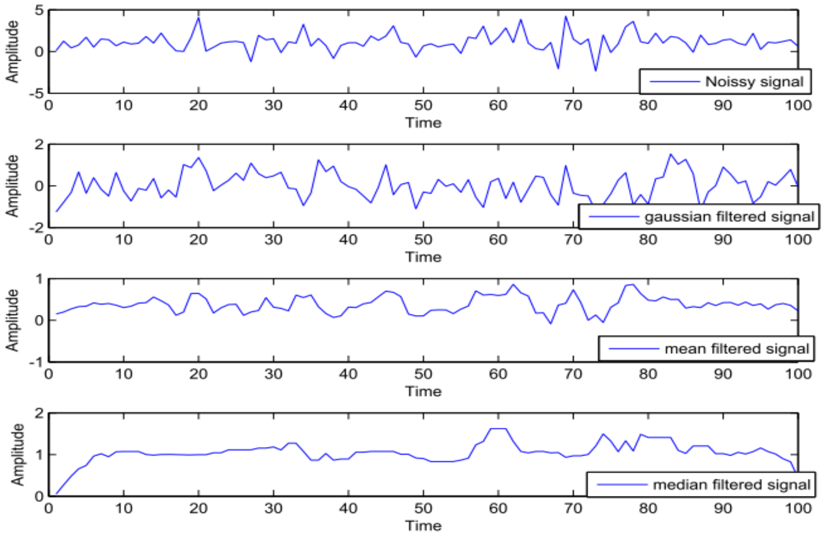

Fig. 11. Simulation of impulse noise signal and filtered signals in time domain.

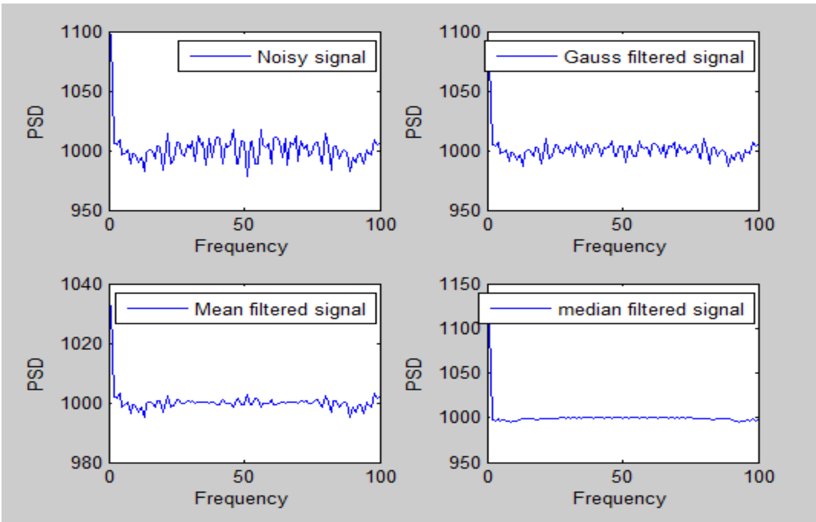

Fig. 12. Simulation of impulse noise signal and filtered signals in frequency domain.

The result depends on the received signal from noisy channel. The signal to noise ratio (S/N) depends on the noise level in the channel so the result of each filter depends on the input signal (in this paper noise of received signal taken randomly).In Table: 2, four readings of each filter have been taken according to noisy signal.

Table: 2several 4 readings of each filter according to noisy signal.

S/N Noisy signal	**S/N Gaussian signal**	**S/N Mean signal**	**S/N Median signal**
6.9054	7.8645	-8.6549	7.5338
7.9054	7.9217	-8.5442	8.5778
8.4534	8.1569	-8.3259	9.3538
9.7687	8.1759	-8.3022	10.0465

IV. Conclusion

In this paper, a framework has been developed for PLC de-noising. Different taxonomies of noises have been illustrated and simulated. Based on that simulation an adequate filter has been designed. In addition, the output signals are simulated in time and frequency domain. The experimental results shows that median is the most dominant filter for the impulse noise as compared to Gaussian and mean filter.

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