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Modelling and Simulation of Noise Effects in Power Line Communications

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Abstract— **Power line communications refers to the concept of transmitting information using the mains power line as a communications channel. Power line communication systems can be simply described as the distribution of data and other signals via electric power distribution wires. There are some challenges for communications over power lines, such as impedance variation, attenuation, channel transfer function varying widely over time, different kind of interference and noise in the system. This Paper deals with the noise scenario modelling approach and modulation schemes for the PLC system.**

Keywords- PLC Channel, Noises, Modulator

I. POWER LINE CARRIER COMMUNICATIONS

Power line Carrier Communications (PLC), or sometimes also referred as Power line Telecommunication (PLT), is a technology that utilizes the existing electrical power distribution network as a transmission medium for communication purposes. Power line carrier communication can be simply described as the distribution of data and other signals via electric power distribution wires. By using this existing cable infrastructure it obviates the need for installation and maintenance of dedicated communication links. Already every building or household is connected to the electrical power grid and more ever; every room has power line contact points installed. Without doubt the extent of this existing infrastructure cannot be matched by any other telecommunication technologies that are available today. As a result, this emerging technology opens up new opportunities for the mass provision of local access at a reasonable cost.

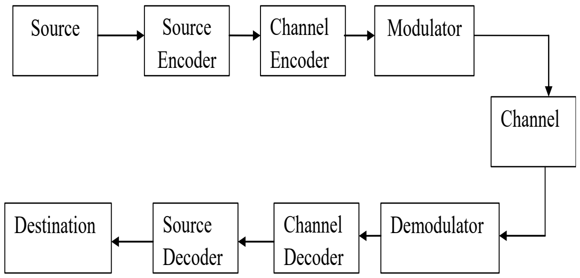

Figure.1. Model of Digital Communication System

II. POWER LINE CHANNEL NOISE

The networks using electrical power distribution lines for voice and data transmission are called Power Line carrier Communication (PLC) networks, which now a day's become more and more attractive. However, like all other technologies, PLC also faces its own set of obstacles and technical challenges. The communication medium of this technology, the power lines, has been designed for transmitting electrical power without any thought on communications. It generally appears as a harsh environment for the low-power high-frequency communication signals. The three important channel parameters, namely noise, impedance, and attenuation, are highly variable with time, frequency, and location [1]. There are some challenges for communications over power lines, such as impedance variation, attenuation, channel transfer function varying widely from time to time and different kinds of interference and noise in the system. Noise in the power line channel is non-additive white Gaussian noise; it includes background noise and impulsive noise. The background noise remains nearly stationary and its power spectral density (PSD) is small. But the impulsive noise has a short duration and a high power spectral density, and it will cause bit errors. [2]

I. Colored background noise, whose power spectral density (psd) is relatively lower and decreases with frequency. [3][4][5]

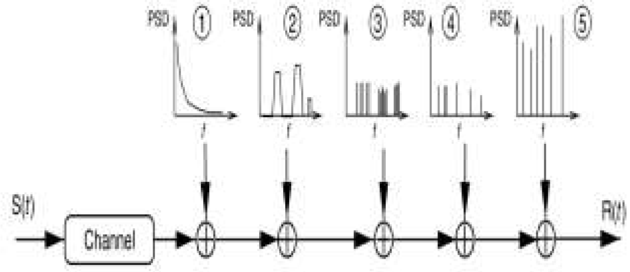

Figure.2. Additive noise types in PLC environments

II. Narrowband noise, which most of the time has a sinusoidal form, with modulated amplitudes. This type occupies several sub bands, which are relatively small and continuous over the frequency spectrum. This noise is mainly caused by the ingress of broadcast stations over medium- and shortwave broadcast bands. Their amplitude generally varies over the daytime, becoming higher by night when the reflection properties of the atmosphere become stronger. [3][4][5]

III. Periodic impulsive noise, asynchronous to the main frequency with a form of impulses that usually has a repetition rate between 50 and 200 kHz, and which results in the spectrum with discrete lines with frequency spacing according to the repetition rate. This type of noise is mostly caused by switching power supplies. A power supply is a buffer circuit that is placed between an incompatible source and load in order to make them compatible. Because of its high repetition rate, this noise occupies frequencies that are too close to each other, and builds therefore frequency bundles that are usually approximated by narrow bands. [3][4][5]

IV. Periodic impulsive noise, synchronous to the main frequency, is impulses with a repetition rate of 50 or 100 Hz and are synchronous with the main power line frequency. Such impulses have a short duration, in the order of microseconds, and have a power spectral density that decreases with the frequency. This type of noise is generally caused by power supply operating synchronously with the main frequency, such as the power converters connected to the mains supply. [3][4][5]

V. Asynchronous Impulsive Noise, whose impulses are mainly caused by switching transients in the networks, These impulses have durations of some microseconds up to a few milliseconds with an arbitrary inter arrival time. Their power spectral density can reach values of more than 50 dB above the level of the background noise, making them the principal cause of error occurrences in the digital communication over PLC networks. [3][4][5]

The achieved measurements have generally shown that noise types I and II remain usually stationary over relatively longer periods, of seconds, minutes and sometimes even of some hours. Therefore, these two can be summarized in one noise class that is seen as colored PLC background noise class and is called "Generalized background noise". The noise types III, IV and V are, on the contrary, varying in time span of milliseconds and microseconds, and can be gathered in one noise class called "impulsive noise", pointed out also in other literatures as "impulse noise".[28]

III. NOISE MODELLING TECHNIQUES

Noise is very hard to be characterized through pure analytical derivation, all of the existing noise models are obtained based on empirical measurements [6][9][15]. Depending on the way measurements are conducted, the noise modelling approaches can be classified into frequency-domain approach or time-domain approach. The frequency-domain approach is based on the measurement of noise frequency spectrum while the time-domain approach is based on measurement of real-valued noise waveforms over time. From the literature, the background noise is mainly modeled in the frequency domain, while the impulsive noise has been characterized in both the frequency and time domain [7].

There are two methods to model the background noise in the frequency domain. The first one is spectrum fitting, where the measured noise PSD [17] or voltage spectrum density [] is fitted into certain functions of frequency. This method captures the average noise spectrum, but it does not provide any information on the random behavior of the noise at each individual frequency.

To do this, statistical analysis method needs to be used [11]-[17] to characterize the background noise variation at each frequency into certain probability density functions (PDFs). This is done so that, with the corresponding statistical parameters of mean and standard deviation, these PDFs can fully describe the statistical characteristics of the noise at a particular frequency. The proposed PDFs in the existing noise models include "sum of two Rayleigh" distribution [19], lognormal distribution [18] and Gaussian distribution [20]. Frequency-domain approaches for impulsive noise modelling are based purely on measurement.

IV. GENERALIZED BACKGROUND NOISE

The modelling of the generalized background noise in the PLC environment, it is considered as the superposition of the colored background noise and the narrowband disturbances; as illustrated in Fig.3. In this case, no difference is made between the short wave radios and the other narrowband disturbances in the form of spectral lines, because normally the spectral lines are found in bundled form as shown in fig.3.

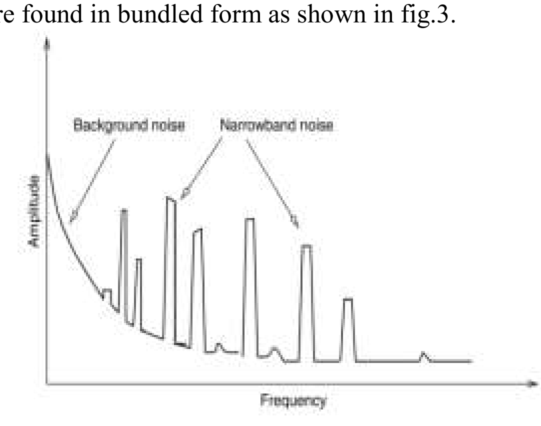

Figure.3. Spectral density models for the generalized background noise\

For the modelling, these bundles of disturbers are approximated by their envelope. Furthermore, because of the high repetition rate noise occupies frequencies that are too close to each other [2], and build therefore frequency bundles that are usually approximated by a narrowband occupation.[25][26]

Therefore, for its modelling, this noise will be seen as a narrowband noise with very low psd. The power density of the colored background noise is time-averaged for the modelling by $N_{CBN}(f)$. the time-dependence characteristic of this noise can be modelled independently with the knowledge of the standard deviation [8]; therefore, the psd of generalized background noise can be written under the following form:

$$N_{GBN}(f) = N_{CBN}(f) + N_{NN}(f) \quad (1)$$

$$N_{GBN}(f) = N_{CBN}(f) + \sum_{k=1}^{B} N_{NN}^{(k)}(f) \quad (2)$$

Where $N_{CBN}(f)$ is the psd of the colored background noise, $N_{NN}(f)$ the psd of the narrowband noise. For the model of the colored background noise psd, the measurements have shown that a first-order exponential function is more adequate, as formulated by Eq. (1), (2).

$$N_{CBN}(f) = N_0 + N_1.e^{\frac{f}{f_1}} \qquad (3)$$

With N_0 the constant noise density, N_1 and f_1 are the parameters of the exponential function, and the unit of psd is dBµV/Hz different investigations and measurements of noise in residential and industrial environments, it was possible to find out approximations for the parameters of this model and the psd of the colored background noise can be described by Eq. (2) and (3): -

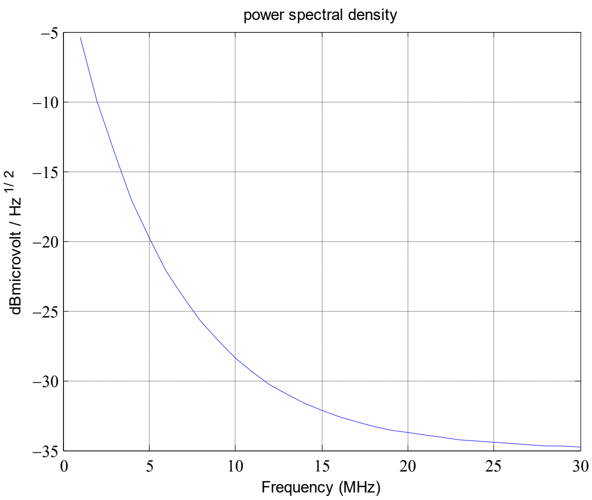

Figure.4. Background Noise

For the approximation of the narrowband noise interferers, the parametric Gaussian function is used, whose main advantages are the few parameters required for specifying the model [26][27].
Furthermore, the parameters can be individually found out from the measurements, which have shown only a small variance. Colored background noise power spectral density (psd) is relatively lower and decrease with frequency as shown in fig.4. Based on the above formulation background noise is simulated using MATLAB program.

V. IMPULSIVE NOISE

The impulsive noise is composed of the periodic impulses that are synchronous with the main frequency and the asynchronous impulsive noise. The measurements show that this class is largely dominated by the last noise type. For this reason, the modelling of this class is based on the investigations and the measurements of asynchronous noise, of which an example is shown in Fig. 3.5. The aim of these investigations and measurements is to find out the statistical characteristics of the noise parameters, such as the probability distribution of the impulses width and their inter arrival time distribution, representing the time between two successive impulses, Fig. 3.6. One approach to model these impulses is a pulse train with pulse width t_w , pulse amplitude A, inter arrival time t_a and a generalized pulse function $p\frac{t}{t_w}$ with unit amplitude and impulse width t_w. [6].

$$N_{imp}(t) = \sum_{i=\infty}^{\infty} A_i\, p(\frac{t - t_i}{t_{w,i}}) \qquad (6)$$

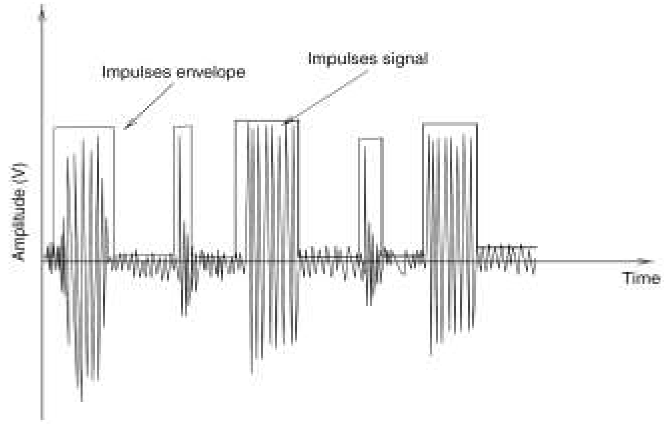

Figure.5. Measured impulses in the time domain in a PLC network

The parameters $t_{w,i}$ A_i and $t_{a,i}$ of impulse i are random variables, whose statistical properties are measured and investigated.

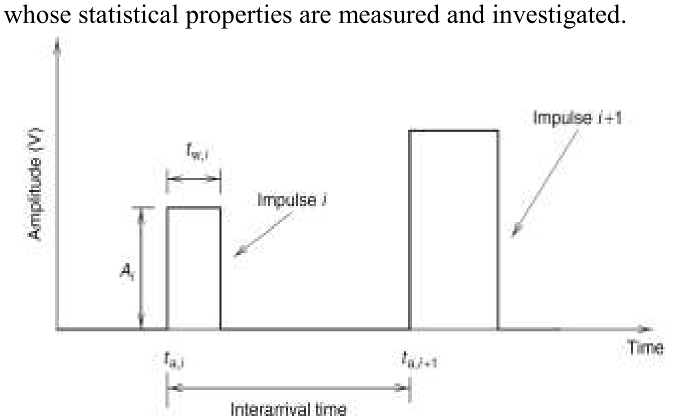

Figure.6. Impulse model used for impulsive noise class modelling

The measurements of the impulse width t_w have also shown that only about 1% of the measured impulses have a width exceeding 500µs and only 0.2% of them exceeded 1ms. Finally, the inter arrival time that separates two successive impulses is below 200 ms for more than 90% of the recorded impulses. Based on the above formulation an impulsive noise is simulated using MATLAB program.

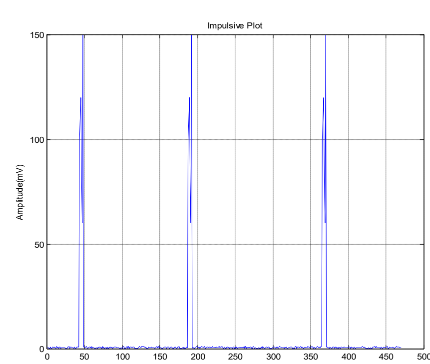

Figure.7. Impulsive Noise

VI. ANALYSIS OF NOISE ON PLC

A. Simulation

Simulation process is performed in matlab program in computer by which realization of the system can be done. There is no need to go in the field and take data from the field in really, through simulation in matlab designing and modelling the PLC is possible in computer. For PLC simulation in different electrical and electronics block of simulation in matlab program is executed. The different blocks is used are Bernoulli binary generator, FSK modulator and demodulator, BPSK modulator and demodulator, PLC channel, Error rate calculation, display, noise, hamming encoder and hamming decoder, etc. MATLAB is a high performance language for technical computing.

It integrates computation, visualization, and programming in an easy to use environment where problem and solution are expressed in mathematical notation. Typical uses include math and computation, algorithm development, data acquisition, modelling, simulation, prototyping data analysis, exploration, visualization, scientific and engineering graphics, application development, including graphical, including graphical user interface building. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. Maintaining the Integrity of the Specifications

B. Modulation Techniques

Modulation is the process of facilitating the transfer of information over a medium. Voice cannot be sent very far by screaming. To extend the range of sound, we need to transmit it through a medium other than air, such as a phone line or radio. The process of converting information (voice in this case) so that it can be successfully sent through a medium (wire or radio waves) is called modulation. Modulation is the process of varying a carrier signal, typically a sinusoidal signal, in order to use that signal to convey information. One of the three key characteristics of a signal is usually modulated: its phase, frequency or amplitude.There is three major classes of digital modulation techniques used for transmission of digitally represented data:

I. Amplitude-shift keying (ASK)
II. Frequency-shift keying (FSK)
III. Phase-shift keying (PSK)

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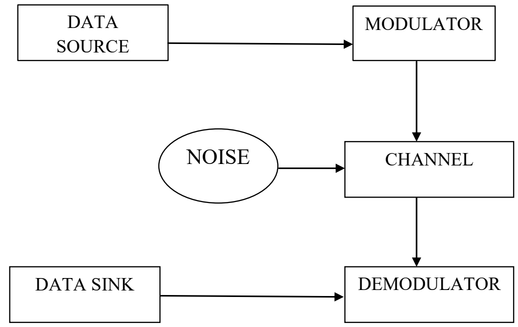


Figure.8. General Model of a communication system

A. *Multipath Model for Power Line Channel*

Multipath effect is a serious problem for PLC because the distribution of power lines is complicated. When signal propagation does not only take place along a direct line of sight path between transmitter and receiver, but additional paths (echoes) are also considered [22][23]. The length of the impulses response and the number of the occurred peaks can vary considerably depending on the environment. This behaviour can be described by an "echo model" of the channel as illustrated in fig. 9.

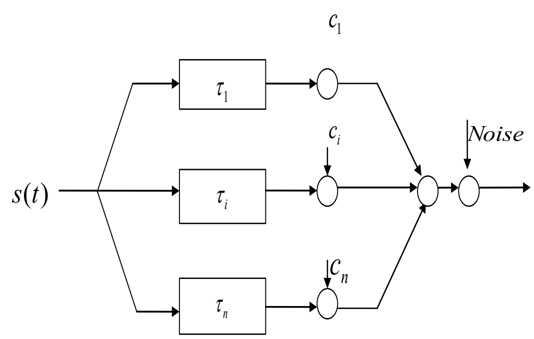


Figure.9. Multipath echo model of the power line

B. *Bit Error Rate*

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate or bit error ratio (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unit less performance measure, often expressed as a percentage. The BER can be considered as an approximate estimate of the bit error probability. This estimate is accurate for a long time interval and a high number of bit errors. In a communication system, the receiver side BER may be affected by transmission channel noise, interference, distortion, bit synchronization problems, attenuation, wireless multipath fading, etc.

VII. Simulation with BPSK Modulation

The simulation of power line carrier communication with BPSK modulation is carried out using simulink. Te BPSK simulation diagram is shown in figure below. For the input signal 10000 bits are generated randomly using binary Bernoulli generator. At receiving end bit error rate (BER) is measured over SNR (dB). Requirement for the BPSK modulation the noise power is kept low, the Bernoulli binary generator generates randomly bits having no. of zero half and no. of one is also half. Bit error rate at different Eb/No is also obtained from simulation

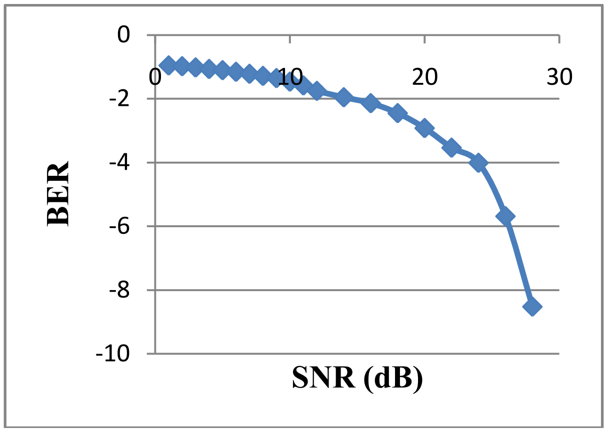


Figure.10. Performance of PLC system under Background noise using BPSK modulation

The performance of power line carrier communication is shown in figure with BPSK modulation at carrier frequency 50 kHz over the SNR ranging from 0 to 28 dB, when we take the background noise. The above figure is plotted with considering with calculation.

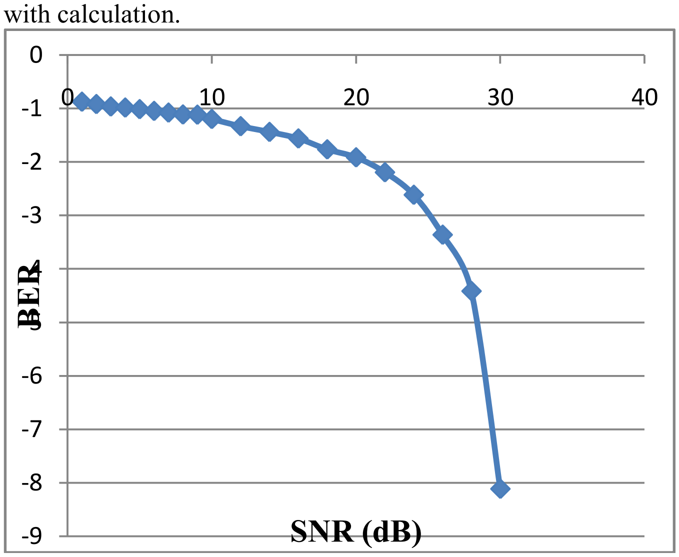


Figure.11. Performance of PLC system under With Impulsive noise using BPSK

VIII. Simulation with FSK Modulation

Frequency-shift keying (FSK) is a standard modulation technique in which a digital signal is modulated onto a sinusoidal carrier whose frequency shifts between different values.The simulations of power line carrier communication with FSK modulation is carried out using Simulink. Te FSK simulation diagram is shown in figure below. For the input signal 10000 bits are generated randomly using binary Bernoulli generator. At receiving end bit error rate (BER) is measured over SNR (dB). Requirement for the FSK modulation the noise power is kept low, the Bernoulli binary generator generates randomly bits having no. of zero half and no. of one is also half.

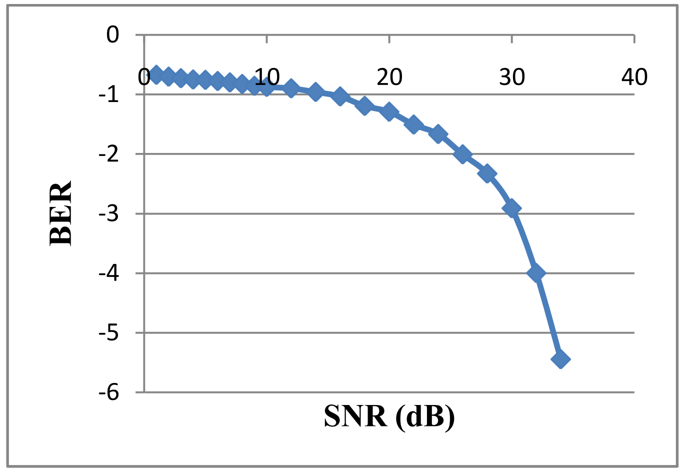


Figure.12. Performance of PLC system under Background noise using FSK modulation

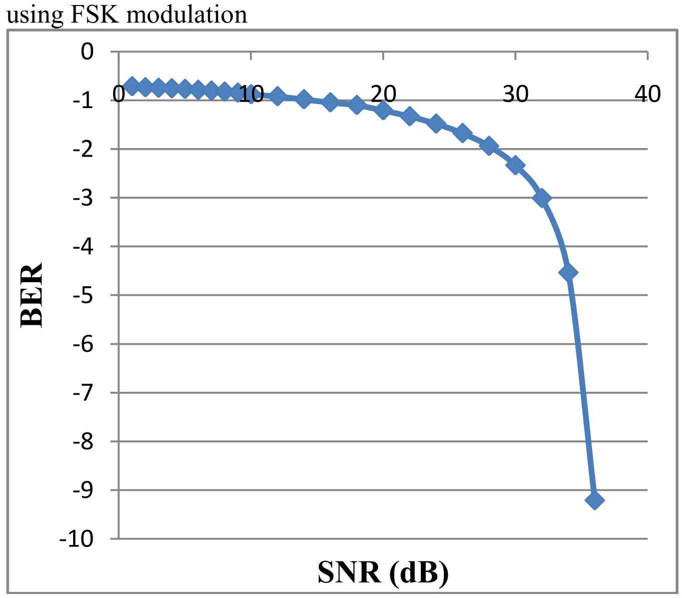
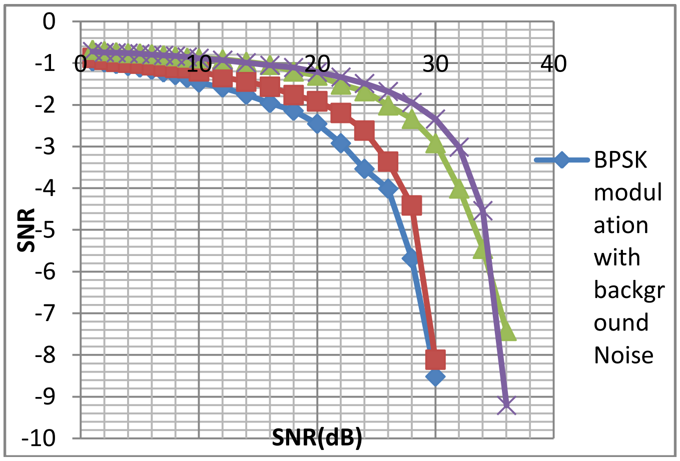


Figure.13. Performance of PLC system under Impulsive noise using FSK modulation

G. Comparison of all modulation scheme with Noises



We have studies the performance of power line carrier communication system. It is found that the performance of power line carrier communication is best with BPSK modulation. We have evaluated the performance of power line carrier communication with different noise such as background noise and impulsive noise with different modulation techniques. It has observed that at a given frequency BPSK system gives best performance as compared to FSK modulation. Our results show that the system is called best because at low SNR regions, where the noise has quite a big power, BPSK system seems to bring the best BER. Proper use of this technology with modulation schemes probably in areas like remote monitoring, home automation, relays, SCADA, fire and security.

IX. CONCLUSION

Power line communication continue to have technical challenges including interference, signal attenuation, noise, lack of standards, and threat to data security for full-scale deployment. Due to the structure of electric power distribution networks, high-frequency signal propagation prone to distortion. Besides signal distortion due to frequency-dependent cable losses and multi-path propagation, noise is the most crucial factor degrading high-speed data transmission over power line networks. In particular, impulsive noise and background noise causes significant time-variant behaviour of the SNR on power line channels. To develop systems which exploit the high channel capacity, the modulation scheme must be selected with care to cope with the peculiar properties of power lines on the one hand and regulatory constraints on the other. Proper selection of values of parameters in different subsection such as source, channel, modulation and demodulation may help to design and implement an efficient communication system

X. FUTURE SCOPE

To overcome the problem of distortion in the PLC system, it is necessary to develop an equalizer using latest intelligent technique.

REFERENCES

[1] H. Meng, S. Chen, Y. L. Guan, C. L. Law, P. L. So, E. Gunawan, and T. T. Lie, "Modelling of transfer characteristics for the Broadband Power-Line Communication channel," IEEE Trans. Power Delivery, vol. 19, no. 3, pp. 1057–1064, 2004.

[2] Halid Hrasnica Abdelfatteh Haidine Ralf Lehnert, "Broadband Power line Communications Networks," Network Design, All of Dresden University of Technology, John Wiley & Sons Ltd, Southern Gate, Chichester, West Sussex PO19 8SQ, England, 2004.

[3] H. Philips, "Modelling of Power Line Communication Channels", Proc, 3rd International symposium on Power line communication and its applications, Lancaster, UK, 1999.

[4] H. Meng, Y. L. Guan, Member, IEEE, and S. Chen, Senior Member, IEEE, "Modelling and Analysis of Noise Effects on Broadband Power-Line Communications," IEEE Transactions on Power Delivery, Vol. 20, no.2, 2005.

[5] A. Voglgsang, T. Langguth, G. Korner, H. Steckenbiller, and R. Knorr, "Measurement, characterization, and simulation of noise on powerline channels," in Proc. 4th Int. Symp, Power-Line Communication and It Applications (ISPLC 2000), pp. 139–146, 2000.

[6] J.G. Proakis, "Digital Communications," McGraw Hill, New York, 2001.

[7] M. Zimmermann and K. Dostert, "A multipath model for power line channel," IEEE Trans. Communication, vol. 50, no. 4, pp. 553-559, 2002.

[8] Masaaki Katayama, Takaya Yamazato, and Hiraku Okada, "A Mathematical Model of Noise in Narrowband Power Line Communication Systems," IEEE Journal on Selected Areas in Communications, Vol. 24, No 7, 2006.

[9] M. Zimmermann and K. Dostert, "A multipath signal propagation model for the power line channel in the high frequency range," in Proc. ISPLC Conf, pp 45-51, 1999.

[10] M. Zimmermann and K. Dostert, "Analysis and modelling of impulsive noise in Broadband Power-Line Communications," IEEE Trans. Electromagn Compat, vol. 44, no. 1, pp. 249–258, 2002.

[11] Yong-tao Ma, Kai-hua Liu, Zhi-jun Zhang, Jie-xiao Yu, Xiao-lin Gong School of Electronic Information Engineering, "Modelling the Colored Background Noise of Power Line Communication Channel Based on Artificial Neural Network," Tianjin University, Tianjin, China vol.12.2004.

[12] M. Goetz, M. Rapp, and K. Dostert, "Power Line Channel characteristics and their effect on communication system design," IEEE Communication Mag., vol. 42, no. 4, pp. 78–86, 2004.

[13] M. Zimmermann, K. Dostert, "An analysis of the broadband noise scenario in power line networks, International Symposium on Power line communications and its Applications," (ISPLC2000), Limerick, Ireland, 2000.

[14] O. G. Hooijen, "On the channel capacity of the residential power circuit used as a digital

communications medium," IEEE Communication Lett., vol. 2, no. 10, pp. 267–268, 1998.

[15] H. C. Ferreira, H. M. Grove, O. Hooijen, and A. J. Han Vinck, "Power Line Communications: an overview," presented at IEEE AFRICON 4th, 1996.

[16] H. Stern & S. Mahmoud, "Communications Systems," Pearson Prentice Hall, 2004.

[17] J. Meng and A. Marble, "Effective Communication Strategies for Noise Limited Power Line Channels," IEEE Transaction on Power Delivery, 2006.

[18] P D. Benyoucef, "A new statistical model of the noise power density spectrum for Power Line Communications," Proceedings of the 7th International Symposium on Power-Line Communications and its Applications (ISPLC), Kyoto, Japan, pp. 136–141, 2003.

[19] A. G. Burr and D. M. W. Reed, "HF broadcasting interference on LV mains distribution networks," in Proc. 2nd Int. Symp. Power Line Communications and its Applications (ISPLC 1998), pp. 253–262, 1998.

[20] D. Liu, E. Flint, B. Gaucher, and Y. Kwark, "Wide band AC Power Line characterization," IEEE Trans. Consum. Electron., vol. 45, no. 4, pp. 1087–1097, 1999.

[21] J.G. Proakis, "Digital Communications," McGraw Hill, New York, 2001.

[22] M. Zimmermann and K. Dostert, "A multipath model for power line channel," IEEE Trans. Communication, vol. 50, no. 4, pp. 553-559, 2002.

[23] Masaaki Katayama, Takaya Yamazato, and Hiraku Okada, "A Mathematical Model of Noise in Narrowband Power Line Communication Systems," IEEE Journal on Selected Areas in Communications, Vol. 24, No 7, 2006.

[24] M. Zimmermann and K. Dostert, "A multipath signal propagation model for the power line channel in the high frequency range," in Proc. ISPLC Conf, pp 45-51, 1999.

[25] M. Zimmermann and K. Dostert, "Analysis and modelling of impulsive noise in Broadband Power-Line Communications," IEEE Trans. Electromagn Compat, vol. 44, no. 1, pp. 249–258, 2002.

[26] Yong-tao Ma, Kai-hua Liu, Zhi-jun Zhang, Jie-xiao Yu, Xiao-lin Gong School of Electronic Information Engineering, "Modelling the Colored Background Noise of Power Line Communication Channel Based on Artificial Neural Network," Tianjin University, Tianjin, China vol.12.2004.

[27] M. Goetz, M. Rapp, and K. Dostert, "Power Line Channel characteristics and their effect on communication system design," IEEE Communication Mag., vol. 42, no. 4, pp. 78–86, 2004.

[28] M. Zimmermann, K. Dostert, "An analysis of the broadband noise scenario in power line networks, International Symposium on Power line communications and its Applications," (ISPLC2000), Limerick, Ireland, 2000.