Evaluation of Adaptive Modulation Technique in PAPR Reduction in OFDM Based High Voltage Power Line Communication Systems

E. Atefat Doost*, M. H. Ghamat**, N. Ghaedi*, M. Golabi**

*Fars Regional Electric Company, Dispatching Group, Shiraz, IRAN

**Dept of EE, School of Engineering, Shiraz University, Shiraz, IRAN

{h_atefatdoost, nghaedi}@frec.co.ir, {m_h_ghamat, m.golabi}@yahoo.com

Abstract— **In High Voltage Power Line Communication (HV-PLC) systems based on adaptive OFDM technique, each subcarrier uses a kind of modulation regarding channel state. In other words, there is a tradeoff between occupied bandwidth and BER in adaptive modulation technique. On the other hand, due to the nonlinearity of transmitter side's power amplifier, one of the main problems of multi-carrier systems is high peak to average power ratio (PAPR), which can cause power dissipation and signal distortion. In this paper defected subcarriers due to nonlinearity of TX side, multipath channel, impulsive and Corona noises are devised to sending PAPR reduction codes for reducing PAPR and BER and at the same time for increasing channel spectral efficiency is evaluated as an effective policy of PAPR reduction. Simulation results show that by using this technique, we can access the higher data rates and reliable services to suppress the PAPR, multipath and impulsive noise effects and attain a lower BERs.**

Keywords— **OFDM, HV Power Line Carrier, Impulsive Noise, Corona Noise, Fading, Channel Estimation, PAPR.**

I. Introduction

By developing of electric power grids and necessity of increasing the security of the electrical energy transmission systems for sending information such as speech, SCADA and measurements data in these systems, a reliable system with high data rate and optimal usage of the available limited bandwidth is vital. One of the thoughtful methods is using a combination of adaptive modulation systems and orthogonal frequency Division Multiplexing (OFDM) technique [1].

In conventional power line carrier (PLC) systems, the modulations with constant rate of sending data on all the subcarriers are used for sending information. While, in the adaptive OFDM techniques, each subcarrier uses adaptive modulation depending on channel's conditions for each subcarrier. In other word, a compromise is made between the efficiency of required bandwidth and the error rate in this technique. The main idea of adaptive modulations is to benefit from fading channel's variations. In this system, instead of considering the sending rate to be constant, the rate of sending and power is set based on the channel's condition.

On the other hand, one of the problems of OFDM systems is the high peak to average power ratio due to non-linearity of power amplifier which causes power dissipation and signal distortion [2].

The adaptive modulation technique was firstly used in DSL wire-lines for maximizing the sending data rate along with OFDM modulation. Since the frequency response of wire-line channel is the relatively time-invariant, the modulation is done for each subcarrier in a relatively long duration; so that side information which should be sent in order to recognize the modulation type on different subcarriers for clarifying the symbols reaches its minimum and this increases the efficiency of this technique. Using adaptive modulation technique in high voltage PLC systems seems more complex and complicated; because of the variable conditions of channel due to switching operations and Corona phenomenon, which cause the SNR level variations on different and subsequent subcarriers through a higher velocity with time and; therefore, it is necessary for the transmitter to follow the channel's variations continuously and this condition needs to send some signals called pilot from the transmitter to the receiver in order to SNR and channel estimation on the subcarriers. On the other hand, the information related to SNR estimation should be sent to the transmitter in order to choose different modulations for different subcarriers, based on the SNR level on different subcarriers [3].

In this paper, regarding the channel's conditions, the modulations with variable rate such as BPSK, QAM, 8-QAM, 16-QAM and 132-QAM; in critical times, no modulation has been used for keeping the bit error rate. Also, the BER errors were simultaneously investigated; which originated from lack of following the channel variations.

II. PLC Communication System Based on OFDM Technique and Adaptive Modulation Through Considering Non-Linear Effects of Channel

The block diagram of the simulated system is as shown in figure (1).

The OFDM signal without cyclic prefix sent on PLC channel is as [1]:

$$s(n) = s(nT) = \sum_{k=0}^{N_c-1} S(k)\exp(j\frac{2\pi kn}{N_c}) \qquad 0 \le n \le N_c\text{-1} \qquad (1)$$

for which $S(k)=a_k+j.b_k$ is k-th M-PSK or M-QAM symbol which is selected adaptively based on the PLC channel's condition and N_c is the number of subcarriers.

The received signal in the receiver side, supposing that the non-linear effect of channel is compensated, is equal to:

$$\underline{r}(n) = \sum_{l=1}^{L} \alpha_l(n) \cdot \underline{s}(n-\tau_l) + \underline{n_{corona}}(n) + \underline{n_{impulsive}}(n) \qquad (2)$$

in which $\alpha_l(n)$ is channel fading coefficient of l-th channel, $s(n)$ is transmitted baseband signal, r(n) is received baseband signal, and $n_{corona}(n)$ and $n_{impulsive}(n)$ are Corona and impulsive noises respectively. The power of Corona and impulsive noises are $\sigma_{corona}^2 = \sigma^2/(1+ICR*p_i)$ and $\sigma_{impulsive}^2 = ICR*\sigma_{corona}^2$, for which σ^2 is the power of the overall noise, which includes corona and impulsive noises, p_i is probability of impulsive noise occurrence and ICR is impulsive to corona noise power ratio. In this paper, according to the given model in [1], the white noise has been used along with spectrum forming filters for modeling Corona noise and also using Poisson's random numbers for modeling the occurrence time of Impulsive noises. Also, the channel's coefficients, the analogous delays through different paths of PLC channel are modeled as in [1]. Since the multipath coefficients and the channel delay are constant and time invariant, according to [1], only one block frame from pilots is sent from transmitter to the receiver for estimating the channel frequency response before beginning the main data sending. Then, the generated bits are modulated on the basis of channel's conditions and SNR rate for different subcarriers which have been sent from the receiver to the transmitter and also regarding the lookup table existing in the transmitter. The modulation type for each subcarrier is selected based on the estimated SNR analogous with that subcarrier. Here, the subcarriers which have been recognized in receiver with weak frequency response are used in transmitter for reducing PAPR. In other words, three subcarriers are always considered among the ones whose frequency response is weak and have the highest separation distance from each other for decreasing PAPR level. In SLM technique [5, 6], eight symbols of OFDM with the same information have been made from each data frame and a frame which has the lowest PAPR level is selected among them. For preventing ISI and ICI, the cyclic prefix is added to the end of each transmitted OFDM symbols, with length of twice the maximum of the received signal's path delays. In the receiver, after removing of cyclic prefix trail, FFT, despreading and channel estimation, the modulation of symbols related to each subcarrier is done and the recovered data are obtained (according to figure (1)). The BER curves are drawn through comparing transmitted and received bits on the basis of Mont-Carlo method. It should be noted that; in this system, the assumption is that the information related to the modulation type used for each one of subcarriers in the transmitter has been sent to the receiver via a secure control channel. In these simulations, the control channel has been simulated with zero error probability. On the other hand, the information related to SNR of different subcarriers has been sent via another control channel to the basis of SNR level of each subcarrier.

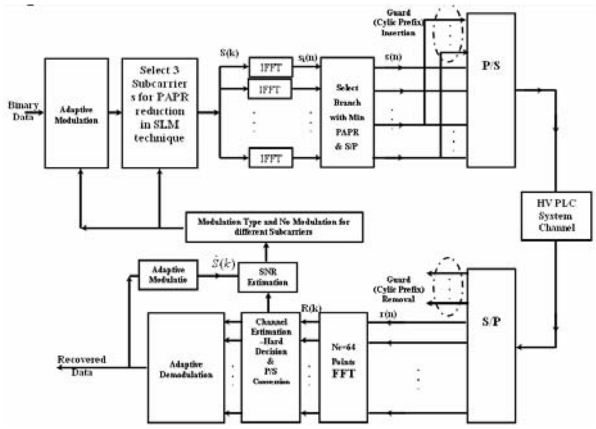

Figure 1. The simulated system model in the adaptive modulation technique based on OFDM technique along with SLM technique.

The performance of adaptive modulation closely depends on the accuracy of channel estimation process. Every kind of error in channel estimation process causes an increase in BER.

In this paper, the recovered data symbols are used for channel estimation; in other words, the recreated bits from symbols modulations are modulated again and are considered as an approximation of the transmitted true data; so that they're used in the SNR estimation process. It should be noted that the SNR estimation process is done after the channel's equalization process. As in [4], the ZF criterion is used for the channel's recovering. In the proposed technique of SNR estimation, the received symbols from the existing source signal in the receiver (the produced bits from the symbols modulation which were modulated again and were considered as an approximation of the transmitted error free signal) become low and; then, their average power is calculated. Afterwards, the noise power is estimated and; finally, the power of the recovered signal is divided to noise power and is used as an approximation of estimated SNR [3]:

$$\text{SNR-estimate} = \hat{\text{SNR}} = \frac{2 \times \left| \hat{S}_k \cdot \hat{H}_k \right|^2}{\text{var}(R_k - \hat{S}_k \cdot \hat{H}_k)} \qquad (3)$$

in which $\hat{H}_k$ and $\hat{S}_k$ are the channel and estimated symbols respectively in receiver and R_k is the received symbols in the receiver's entrance. The noise signal power is equal to variance of the difference between received signal R_k, and estimated signal in the receiver side. In figure (2), the estimated SNR has been drawn on the basis of the real SNR in the AWGN channel. It is observed that the technique described in AWGN channel had a relatively good performance in SNR estimation.

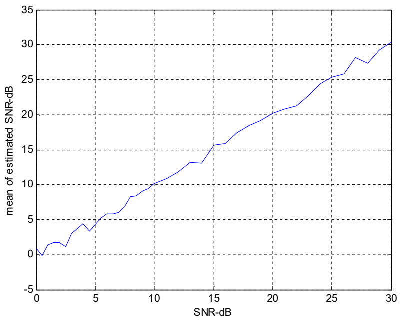

Figure 2. The estimated SNR versus true SNR in AWGN channel.

In SLM techniques, a number of subcarriers should always be allocated to decreasing PAPR which itself causes a part of channel's capacity to be wasted. In the SLM technique which is known as a distortion-less technique, the transmitter produces different number of data blocks (M) from the main data block all of which transmit the same information. Then, among these blocks, a block which has the lowest PAPR is sent on the transmitter side. In this proposed technique, which has been shown in figure (1), the defective subcarriers which are null and don't convey any information, are used for decreasing PAPR. In the suggested technique, in the location of considered subcarriers; one time; symbol 1 and the other time; symbol -1 is used in order to decrease PAPR; so that $M=2^k$ (the created frame) which has the lowest PAPR is sent on the channel in order to decrease PAPR. In this paper, the Rapp's model [5] has been used for modeling the non-linear effects of power amplifiers through the transmitter path. The Input Back Off characteristics of the amplifiers for IBO=4, and IBO=10 have been taken into account.

III. Simulation Results

Assuming perfect timing synchronization, bit-error-rate (BER) simulation with about 10^6 bits in HV PLC channel is examined by Monte-Carlo method. Simulation parameters are as in table I. Total 10^6 data bits are simulated and BER is gained from comparing the hard-decision demodulated symbols with the true symbol constellations.

The simulation results are shown in figures (3), (4), (5) and (6). In figure (3), the functionality of different modulations have been given in HV-PLC system on the basis of OFDM technique with a non-linear effect of amplifier in the transmitter (IBO=4). Meanwhile, for the voice communication services, the minimum threshold of SNR is chosen through $BER=10^{-2}$ for changing the modulation type among the following modulations BPSK, QAM, 8-QAM, 16-QAM and 32-QAM regarding these graphs for adaptive modulations in different conditions in figures (4) and (5). The channel estimation based on block pilot structure in PLC channel doesn't have suitable functionality and it's because of the sensitivity and dependency of SNR estimation algorithm to the HV-PLC channel estimation. Also, we have the channel estimation error because of the impulsive and Corona noises which are variable with time. Meanwhile, for reaching more accurate channel estimation, a higher SNR should be considered about 15 dB) and; in fact, the exchange between bit rate and the sending signal power should be considered. It should be mentioned that the fluctuations existed in figures (4) and (5) have originated from the modulation level increment in the threshold areas of modulation change, which has been determined in previous stage.

TABLE 1. SIMULATION PARAMETERS

Parameters	Value	
Bandwidth	400 KHz	
Distance (space) between Subcarriers (Δf)	6.25 KHz	
Tfft	64	160 µs
Cyclic prefix	4	10 µs
Symbol Length	68	170 µs
Number of data Subcarriers	52	
Total Number of subcarriers	64	
Modulation	Null (No) Modulation, BPSK, QAM, 8-QAM, 16-QAM, 32-QAM,	

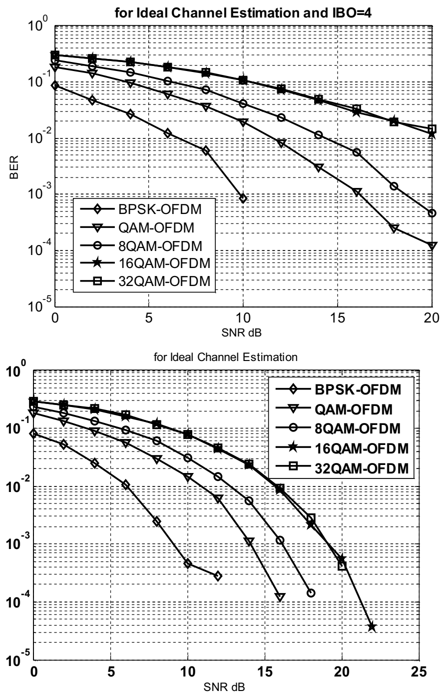

Figure 3. BER curves in OFDM based HV-PLC system, using ideal channel estimation method and IBO=4 & IBO=10.

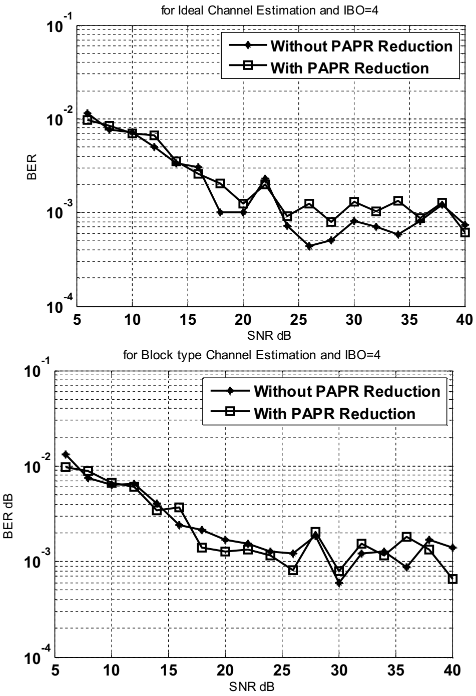

Figure 4. BER curves in adaptive OFDM based HV-PLC system, using ideal and block type channel estimation methods, with and without PAPR reduction technique with IBO=4.

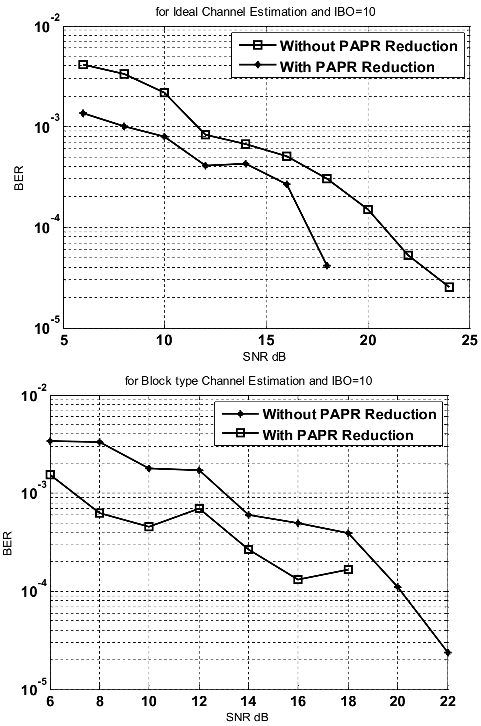

Figure 5. BER curves in adaptive OFDM based HV-PLC system, using ideal and block type channel estimation methods, with and without PAPR reduction technique with IBO=10.

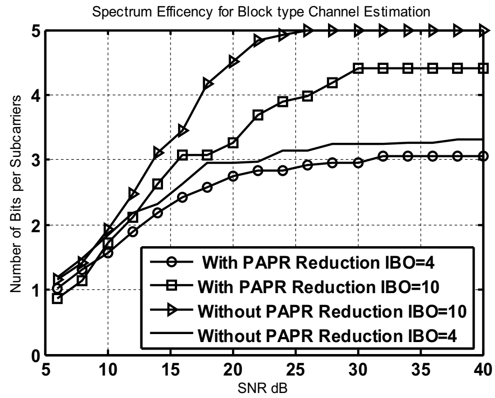

Figure 6. Bandwidth efficiency of adaptive modulation technique using PAPR reduction technique in HV-PLC system with IBO=4 and IBO=10.

In figure (6), the bandwidth efficiency parameter (the average ratio of the whole number of transmitted bits to the whole number of existing subcarriers for sending data) of the adaptive modulation technique has been given along with PAPR reduction technique in HV-PLC system based on OFDM adaptive technique with parameter IBO=10. As it can be seen, the algorithm of adaptive modulation along with the technique of PAPR reduction for SNR level of higher than 15 dB has a higher spectral efficiency (higher than 3) and this matter shows the superiority of adaptive modulation technique in comparison with the system without adaptive modulation for SNR level of higher than 15 dB.

IV. Conclusions

In this paper, different components of the baseband part of OFDM system in high voltage power line communication system have been simulated. The simulation results in HV-PLC channel show that the overall efficiency of the system can be increased by about 4dB through using defected subcarriers (without sending information symbols) for adding the PAPR reduction codes. Since the SNR estimation algorithm – which is used in the adaptive modulation operations and finding the place of subcarriers without data- is sensitive to the channel estimation process; it is necessary to estimate an accurate channel estimation through the attendance of impulsive and Corona noises in order to reach a high accuracy in SNR estimation; so that the block channel estimation algorithm, which is done only for the first transmitted OFDM symbol, can provide the possibility of modulation change from BPSK to higher- level modulations in the transmitter side only in high SNRs (about 10 dB and higher ones). Meanwhile, it can be seen that by using SLM technique with code length of 3, the BER rate is decreased effectively in OFDM system.

References

[1] H. Atefat Doost, M. H. Ghamat, A. Rafiei "Robustness Evaluation of OFDM and MC-DS-CDMA Systems in Digital High Voltage Power Line Communication Systems by Using LS Channel Estimation Technique", 3rd IEEE International Conference on Information &

Communication Technologies: from Theory to Applications, ICTTA'08, April 7-11 2008, Damascus, Syria.

[2] M. H. Ghamat, H. Atefat Doost, A. R. Zolghadr-asli, “Selection of Suitable Equalizer and PAPR Reduction Technique for OFDM Based Power Line Communication Systems”, 15th Iranian Conference on Elec. Eng. (ICEE2007), Tehran, Iran, (In Persian).

[3] L. Liu, P. L. So and E. Gunawan "Performance Analysis of a Combined Adaptive OFDM Transmission Scheme for Broadband Power Line Communications", ICICS 2005, pp. 926-930, 2005.

[4] S. Coleri, M. Ergen, A. Puri, A. Bahai, “Channel Estimation Techniques Based ob Pilot Arrangements in OFDM Systems”, IEEE Trans. On Broadcasing, Vol. 48, No. 3, pp. 223-229, September 2002.

[5] A. ZOU ALGHADR ASLI, M.H. GHAMAT "AN OVERVIEW OF PAPR REDUCTION TECHNIQUES FOR MULTICARRIER TRANSMISSION AND PROPOSE OF NEW TECHNIQUES FOR PAPR REDUCTION " IRANIAN JOURNAL OF ELECTRICAL AND COMPUTER ENGINEERING, pp. 115, Summer-Fall 2008.

[6] J. Sun Lee, H. M Oh, J. T Kim and J. Y. Kim, “Performance of Scaled SLM for PAPR Reduction of OFDM Signal in PLC channels”, IEEE International Symposium on Power Line Communications and Its Applications, pp. 166-170, 2009.