Influence of Chaotic spreading factor modulation based Random Modulation on G3-PLC system

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***Abstract* – With the expansion of the smart grid, smart meters became played a vital role in monitoring and supervising the grid system. To ensure the continuity of the monitoring and controlling of the smart meters, it's essential to ensure that the communication system operates properly. However, smart meters communication modules face interfering noises from the surrounding equipment. Those interfering noises can adversely affect the communication systems and cause loss of data. This paper introduces chaotic spread spectrum techniques aimed to reduce the interfering noises produced by DC-DC buck converter on G3 power line communication system.**

Index Terms – Power line communication, Spread spectrum, Chaotic modulation, Smart meters, Random modulation, Spreading factor, Smart grid.

I. INTRODUCTION

With the energy sustainability vision, the smart grid became very important. The European Union dedicated a lot of investments to implementing smart grids and encouraging the deployment of smart meters. In 2014, the European joint research center report stated that there are more than 459 projects regarding the smart grid in the European Union [1, 2]. With this exponential deployment of smart meters, a lot of research became investigating the problems that cause failure in the operation of the smart meter. Those problems can be classified as hardware, software, and communication problems [3, 4]. Communication problems are the most common, especially in the complex smart grid environment, which includes a lot of interconnection between several devices with various communication topologies. Power line communication (PLC) is one of the most commonly used communication protocols, it is used in both electronic and automated meters [5- 7]. One of the main advantages of PLC is that it does not require extra installation costs as it uses the existing electrical network to transfer the data [6]. However, PLC systems suffer from the noises conducted by the surrounding electrical equipment [8- 10].

On the other hand, the power converters conducted/radiated emissions affect the PLC significantly as the PLC operates in CENELEC-A which operates within 3 – 95 kHz while most power converters operate at switching frequency below 150 kHz. Also, the civilian electromagnetic compatibility standards cover the converters operating after 150 kHz [8]. Operating at similar frequency ranges makes the power converters conducted/emitted electromagnetic interference (EMI) adversely affect the PLC system and cause lot of losses in the received data, service misreading, and interruption of service [10]. Therefore, it is important to mitigate the emissions of power converters [11]. One of the methods used to reduce the converter's emissions is using randomized modulation [12, 13]. Conventional modulation techniques have high harmonic contents due to the fixed on/off duty cycle. Therefore, random modulation is preferred as it can change the density of the spectral power to reduce the harmonic property [13]. Thus, random modulation is used in many applications such as machine torque ripples reduction and lowering the acoustic noise [14]. A lot of researches investigated various ways to apply random modulation such as randomizing the switching frequency, randomizing the pulse position, and randomizing the pulse width [10- 14].

This paper aims to present chaotic hybrid random modulation schemes and show their ability to reduce the interference in G3-PLC system. The chaotic hybrid random modulation is based on introducing hybrid spreading spectrum schemes. The hybrid spreading spectrum schemes are based on the combination of the most famous modulation carriers which are triangular, sinusoidal, and phase-amplitude modulation (PAM). The performance of those hybrid schemes is assisted by measuring the rate of transmitted data error under three different sampling rates. The paper is organized as follows, Section II discusses the implementation of the spread spectrum, while Section III provides the practical results under three sampling step sizes and analysis Finally, Section IV concludes the work done.

II. RANDOMIZED MODULATION

The Random Carrier Frequency Modulation with Fixed Duty Cycle (RCFMFD) approach is considered in this paper as it's popular and simple [10]. The spread spectrum switching signal $Sw(t)$ of the randomized carrier frequency is presented in equation (1).

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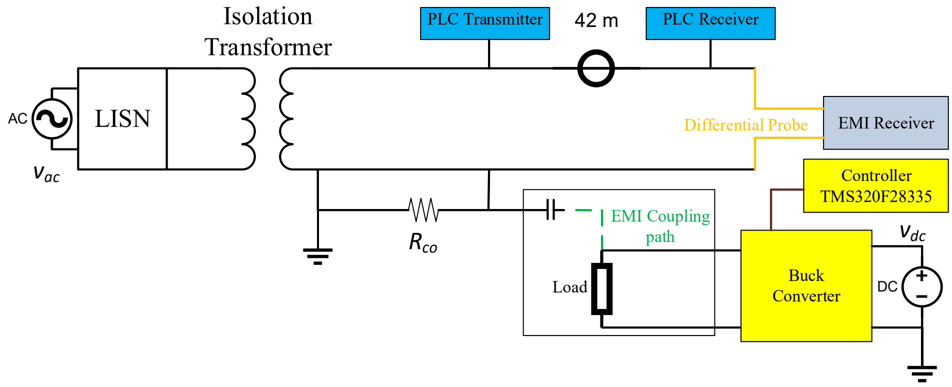

Figure 1. Test rig structure

$$Sw(t) = A_{car} \cos\left(2\pi f_{car} t + 2\pi \Delta f_{dev} \int_{-\infty}^{t} \varepsilon(t)\, d\tau\right) \quad (1)$$

Where, $\varepsilon(\tau)$: Driving signal

A_{car} : The amplitude of the carrier frequency.
Δf_{dev} : Frequency deviation surrounding the main switching frequency.
f_{car} : Carrier frequency

From equation (1), it can be deduced that tuning any of those parameters can lead to randomized modulation. For tuning the deviation of frequency around the main switching frequency (the signal bandwidth), equation (2) is used.

$$\Delta f_{dev} = \alpha f_{ds} \quad (2)$$

Where 'α' is the spreading factor used to set the required frequency bandwidth.

The driving signal $\varepsilon(\tau)$ consists of N point that forms its shape, varies from -0.5 to +0.5. The frequency change by a certain sampling step time within the given range, and can be obtained from equation (3),

$$t = \frac{k}{t_s} \quad (3)$$

Where 'k' is a Prescaler factor. Hence, The frequency f_{ds} of the driving signal $\varepsilon(t)$ is presented in equation (4).

$$f_{ds} = \frac{1}{t \times N} \quad (4)$$

Studying the influence of changing the spreading factor and the driving signal frequency rate on the G3-PLC channel performance is considered in this research work. However, instead of using a constant value spreading factor, the spreading factor is randomly varied based on the combinations of the primary and secondary signals presented in Figure 2. It can be seen from Figure 2 that the primary signal has "0.4" amplitude and shifted in order to have positive values only while the second signal has (0.5 to -0.5) amplitude. These modulation amplitudes were chosen in order to enhance the effect of random modulation carriers on the G3-PLC system.

III. Proposed System Structure And Results

The implemented system is shown in Figure 1. The G3-PLC modules are connected through a 42-meter cable.

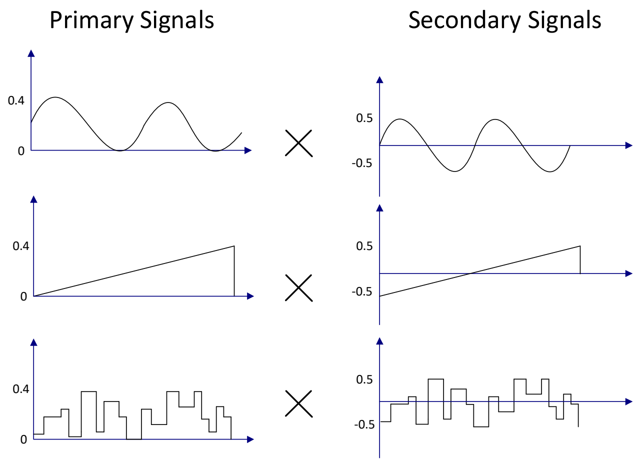

Figure 2. Random spreading factor signals combinations.

The supply voltage is filtered through a line impedance stabilization network (LISN) and isolating transformer. The source of noise is a DC-DC buck converter.

The buck converter is coupled to the main circuit through a parasitic capacitor providing the parasitic path. The buck converter is controlled by a TMS320F28335 DSP controller while Microchip PL360 is used as the G3-PLC communication modem. The system parameters are presented in Table I.

Table I: Experimental parameters.

v_{dc}	50 V	
v_{ac}	220 V	
R_{co}	2 Ω	
Load	35 Ω	
Parasitic capacitor	10 nF	
Main switching frequency	63 kHz	
Buck output voltage	25 V	
EMI Receiver settings	Detector type	Average detector
	RBW	200 Hz
PLC parameters	Type	G3 (35 kHz – 91 kHz)
	Frames sent	1000
	Delay time	100 mS
	Modulation	OFDM
	Mapping	BPSK
	Carrier Frequency	1.5 kHz

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The practical setup used to obtain the following results is presented in Figure 3.

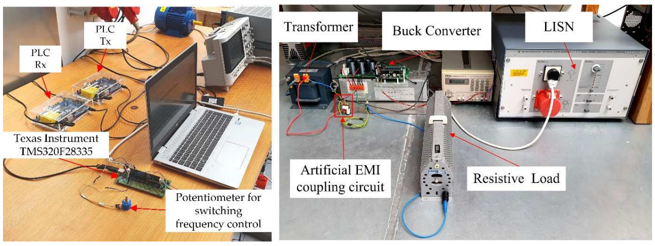

Figure 3. Practical setup.

The applied chaotic hybrid modulation schemes and their associated emissions levels are presented in the following figures.

Figure 4a presents the output signals while the main signal was the sinusoidal signal. It can be noticed that the multiplication of two sinusoidal signals depicted what seems to be a level-shifted sinusoidal signal with some deviations. Figure 4b shows the emissions associated with those techniques and it can be seen that the multiplication of two Sinusoidal signals caused a shifting in the emissions to the edge of 63 kHz instead of being concentric around it as in [10].

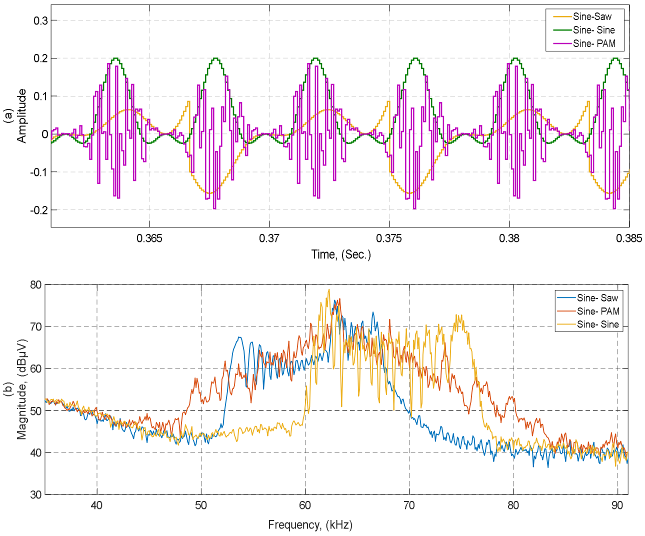

Figure 4. Hybrid modulations are based on Sinusoidal modulation.

Figure 5a shows the product of two signals while the Sawtooth signal is the primary signal and figure 5b shows the emissions of this modulation. In Figure 6a, the primary signal is PAM. It is also seen from Figures 4b and 5b that the emissions were shifted when two signals of the same modulation type were multiplied.

In order to evaluate the effectiveness of those techniques, the frame error rate (FER) between the G3-PLC transmitter and receiver is calculated for each of those techniques under three different driving signals frequency rates as presented in Table II.

The tests were undertaken with a signal to interference ratio ranging from 2.5 dB to 4.5 Db. The presented three cases were chosen to illustrate the influences of the emissions in the case of using driving signal frequencies around the subcarrier frequency of the G3-PLC “1.5 kHz”. This means that the FER is expected to be higher at 3 kHz due to the interference between the G3-PLC and converter frequencies.

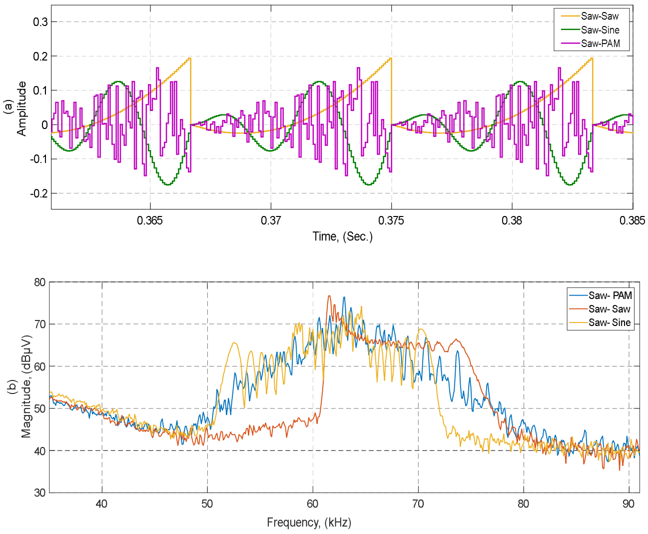

Figure 5. Hybrid modulations based on Sawtooth modulation.

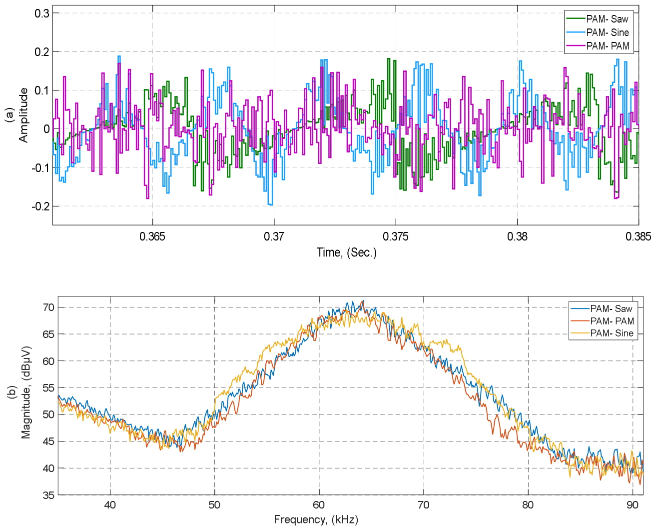

Figure 6. Hybrid modulations based on PAM.

Table II The channel FER under the influence of using the chaotic hybrid modulation techniques.

Spreading tech. \ Freq. of sampling	30000 Hz	12000 Hz	3000 Hz
Sine_PAM	FER= 0%	FER= 4%	FER= 35%
Sine_Sine	FER= 0%	FER=37%	FER=42%
Sine_Saw	FER=28%	FER=76%	FER=78%
Saw_PAM	FER=59%	FER=66%	FER=59%
Saw_Sine	FER=91%	FER=32%	FER=82%
Saw_Saw	FER=56%	FER=83%	FER=83%
PAM_PAM	FER=66%	FER=26%	FER=61%
PAM_Sine	FER=68%	FER=65%	FER=62%
PAM_Saw	FER=68%	FER=64%	FER=59%

From table II, it can be deduced that the “Sine_PAM” combination seemed to give the best results even when it was influenced by the interference of the G3-PLC subcarrier frequency at 3 kHz as one-third of the data transmitted wasn’t received. The “Sine_PAM” combination also has the lowest FER compared to the other hybrid techniques.

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Also in comparison with the results of the fixed spreading factor technique presented in [8] the "Sine_PAM" has better results and lower FER than most of them. The level-shifted "Sine_Sine" combination causes data losses at low frequencies. The combinations based on the primary Sawtooth signal didn't achieve pleasant results and caused significant data losses. Besides, the combinations based on the PAM signal cause high data losses.

Therefore, it was tested to amplify the previous combinations of signals by amplifying the primary signals to reach a max amplitude of 0.6 instead of 0.4. This will lead to a shift in the emissions associated with those signals. The amplified "Sine_Sine" and "Saw_Sine" signals are presented in figure 7 while the influence of those amplified signals on the G3-PLC is presented in Table III. Those signals were chosen as they had enhanced performance after the amplification process.

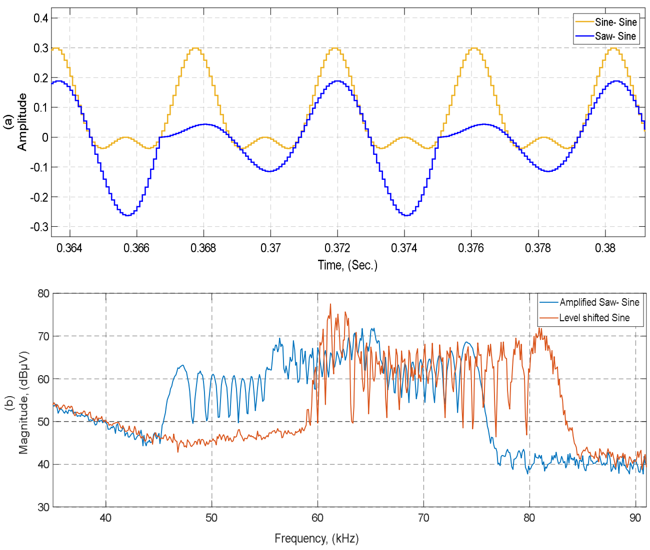

Figure 7. Hybrid modulations based on PAM.

Table III: FER under the influence of using the amplified chaotic hybrid modulation techniques.

Spreading tech. \ Freq. of sampling	12000 Hz	3000 Hz
Sine_Sine (Level shifted)	FER= 0%	FER= 0%
Saw_Sine	FER= 0%	FER= 80%

From Table III, it can be seen that after the amplification of the combination based on the Sawtooth signal, the FER became zero at a sampling frequency of 12 kHz while it fell dramatically at 3 kHz due to the interference with the G3-PLC subcarrier frequency. Meanwhile, the chaotic level-shifted based on sinusoidal signal had a significant performance at both 12 kHz and 3 kHz with an almost zero error rate.

IV. Conclusion And Future Work

In this paper, various chaotic hybrid signals were formulated as a randomized spreading factor representing a randomized modulation. It was shown that in most of those techniques EMI caused a lot of data loss through the G3-PLC receiver. It was also proven that the hybrid schemes based on primary sinusoidal signals had an efficient performance at the three sampling frequencies concerning the G3-PLC error rate. In order to overcome the interference with the G3-PLC subcarrier frequency, the amplified chaotic level-shifted sinusoidal signal was presented and it had a very efficient performance up to 3 kHz. The future work of this study is to build curves for the previously presented techniques and attenuate/amplify the signals with different ratios to reach the optimum operating points of each technique and define its boundaries

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