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A User - Friendly Signal-Processing App For Harmonics

Harmonikler İçin Kullanıcı Dostu Bir Sinyal İşleme Uygulaması

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ABSTRACT

Harmonics, especially the $3^{rd}, 5^{th}$, and 7^{th} components are significant disturbances in power systems, occurring simultaneously and at varying time intervals. Measurements of these components depend on factors such as fundamental frequency deviation, event duration, amplitude values, and noise levels. Accurate detection and measurement are crucial for effective harmonic mitigation and preventive strategies. This study introduces a harmonic signal analysis application utilizing methods like FFT, STFT, CWT, EMD, and HHT, with individual user interfaces for in-phase and time-variant harmonic signals. The application provides results for amplitude, frequency, event time intervals, and noise effects simultaneously. Test results at a 60 dB signal-to-noise ratio (SNR) reveal that FFT achieves precise frequency and amplitude results due to its high resolution, whereas other methods offering time-frequency domain results exhibit lower resolution. EMD, in particular, demonstrates high errors in frequency and amplitude responses, reducing four frequency components to three. HHT, utilizing EMD results, yields higher accuracy with minimal errors compared to other methods. This application, combined with test results, facilitates signal synthesis and comparative analysis in time and time-frequency domains.

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ÖZET

Harmonikler, özellikle 3., 5. ve 7. bileşenler, güç sistemlerinde aynı anda ve değişen zaman aralıklarında meydana gelen önemli bozulmalardır. Bu bileşenlerin ölçümleri temel frekans sapması, olay süresi, genlik değerleri ve gürültü seviyeleri gibi faktörlere bağlıdır. Etkin harmonik azaltma ve önleyici stratejiler için doğru tespit ve ölçüm çok önemlidir. Bu çalışmada, FFT, STFT, CWT, EMD ve HHT gibi yöntemleri kullanan, faz içi ve zaman değişkenli harmonik sinyaller için ayrı kullanıcı arayüzlerine sahip bir harmonik sinyal analizi uygulaması tanıtılmaktadır. Uygulama aynı anda genlik, frekans, olay zaman aralıkları ve gürültü efektleri için sonuçlar sağlar. 60 dB sinyal-gürültü oranındaki (SNR) test sonuçları, FFT'nin yüksek çözünürlüğü nedeniyle hassas frekans ve genlik sonuçları elde ettiğini, oysa zaman-frekans alanı sonuçları sunan diğer yöntemlerin daha düşük çözünürlük sergilediğini ortaya koyuyor. Özellikle EMD, frekans ve genlik yanıtlarında yüksek hatalar göstererek dört frekans bileşenini üçe indiriyor. EMD sonuçlarını kullanan HHT, diğer yöntemlere kıyasla minimum hatayla daha yüksek doğruluk sağlar. Test sonuçlarıyla birleştirilen bu uygulama, zaman ve zaman-frekans alanlarında sinyal sentezini ve karşılaştırmalı analizi kolaylaştırır.

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1. INTRODUCTION

Within the field of power systems, the main amplitude and frequency emerge as some elements, necessitating compliance with prescribed standards [1-4]. Nevertheless, fluctuations in parameters like frequency and amplitude occur intermittently, influenced by various system components such as different types of electrical motors, lamps, switching, and lighting elements, nonlinear loads and arc furnaces, etc [5-8]. Extensive scholarly endeavors have scrutinized this issue, focusing on detailed analyses and classifications [9-12].

IEEE 1159 and 1459 emphasize parameters for power quality and the interpretation of related measurements. Documents like IEC 61000-4-7 and -4-30 guide on testing and evaluating disturbances in power systems, with the latter allowing a 0.2-second window for analysis.

Notably, in-phase harmonics and time-variant harmonics may manifest in power systems. With odd-order, mostly the $3^{rd}, 5^{th},$ and 7^{th} harmonics hold significant prominence as defined by IEC 61000-4-7. These harmonics, appearing either singularly or multiply, can align with the fundamental component and exhibit temporal variations, thus posing inherent risks and leading to potential measurement inaccuracies [1-4]. Periodic monitoring and harmonic analysis are imperative due to the potential for inaccuracies to compound issues, including challenges in determining the component values for elimination.

The efficacy of robust correction mechanisms, incorporating filtration and compensation, hinges upon sophisticated signal processing techniques. The most popular technique is Fast Fourier Transform (FFT) which can analyze a signal in the frequency domain. The other techniques, Time Fourier Transform (STFT) and Continuous Wavelet Transform (CWT) are usable for the time-frequency domain. Another technique, Hilbert Huang Transform (HHT) based on Empirical Mode Decomposition (EMD) also assures time-frequency analysis while EMD provides only individual time domain analysis for each frequency component. Hereby, the appropriate signal processing method selection is of great importance.

This paper endeavors to compare the mentioned methods for signal processing, in the context of addressing harmonics under conditions of in-phase and time variation. For this aim, an application on the harmonics synthetizes and analysis has been proposed.

Structurally, this paper unfolds as follows: initial elucidation on power quality and the delineation of different harmonic types, followed by an exposition on different time- and time-frequency-based methods augmented by illustrative visual representations of signal processing responses to harmonic-laden signals. The user-defined and pre-defined interfaces of the application proposed for these signals, which are produced for signals with in-phase and time-variant harmonics, are explained. Afterwards, the responses and results obtained from these interfaces and these responses and results were discussed. Finally, a comprehensive summary encapsulates the key insights gleaned from this discourse.

2. POWER QUALITY AND HARMONICS

The main amplitude and frequency which should be 220 V_{rms} and 50 Hz in Turkey are crucial parameters. However, odd-order harmonics such as $3^{rd}, 5^{th},$ and 7^{th} stated in IEC 61000-4-7, may falsify them. These can appear singularly or multiply, in phase with the main signal, or at different moments.

Main Frequency and Amplitude Variation

Variations on main amplitude and frequency are typified by α and f_{line} in Eq. (1). Detrimental and undesirable outcomes may occur owing to these variations. It is important to adhere to this equation when modeling the power system voltage.

$$x(t) = \alpha\sin\left(2\pi f_{line} t\right), \qquad \alpha = 220\, V_{rms}, f_{line} = 50\, Hz \tag{1}$$

Harmonics

Harmonics are present intensely in power systems. Degradation of their effect is crucial for the systems. The primary culprits are the $3^{rd}, 5^{th},$ and 7^{th} harmonics, which require continuous monitoring. This issue is addressed in two sections: in-phase and time-variant.

a. In-phase harmonics: Eq. (2) presents a signal that includes in-phase harmonics, with coefficients $\alpha_3, \alpha_5,$ and α_7. Figure 1 illustrates the in-phase harmonic signal.

$$x_1(t) = \alpha_1 \sin(2\pi f_{line} t) + \alpha_3 \sin(2\pi 3 f_{line} t) + \alpha_5 \sin(2\pi 5 f_{line} t) + \alpha_7 \sin(2\pi 7 f_{line} t) + noise_{SNR}(t), \qquad \alpha_n = \frac{1}{n}, n = 3,5,7 \tag{2}$$

b. Time-variant harmonics: A time-variant harmonics signal behaves according to the mathematical model as in Eq. (3). $u(t_k)$ formulates the initial and stop points of the harmonic events. Figure 2 shows a time-variant harmonics- signal.

$$x_2(t) = \alpha_1 sin(2\pi f_{line}t) + \alpha_3\, sin(2\pi 3 f_{line}t)\big(u(t_1) - u(t_2)\big) + \alpha_5\, sin(2\pi 5 f_{line}t)\big(u(t_3) - u(t_4)\big) + \alpha_7\, sin(2\pi 7 f_{line}t)\big(u(t_5) - u(t_6)\big) + noise_{SNR}(t), \quad \alpha_n = \frac{1}{n}, n = 3,5,7 \quad 0 \leq\ t_k, \leq 0{,}2\ sec, k{=}1{:}6 \quad u(t_k): unit\ step\ function \tag{3}$$

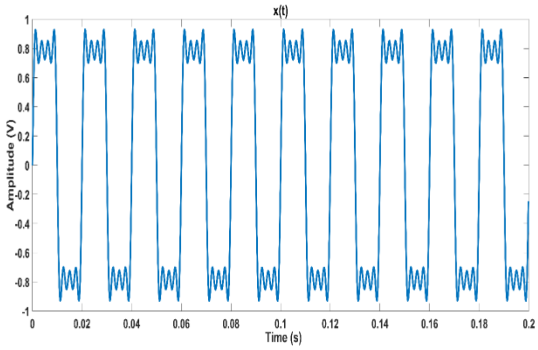


Figure 1. An inphase harmonics – signal.

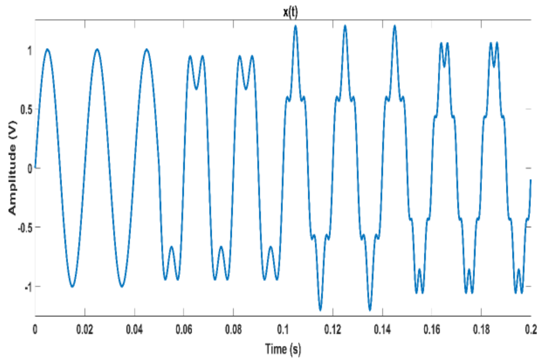


Figure 2. A time-variant harmonics – signal.

3. METHODOLOGIES FOR SIGNAL PROCESSING

For power systems, instant harmonics monitoring and analysis are vital. These must be tracked and analyzed periodically in detail. The selection of an efficient and robust technique for the time-varying signals is important for precise analysis, filter design, or system compensation. Several common ones are handled in this paper as follows.

a. Fast Fourier Transform (FFT): FFT of x and its length are defined as y and L as follows:

$$y(k) = \sum_{j=1}^{L} x(j) W_L^{(j-1)(k-1)},\ W_L = e^{(-2\pi i)/n} \tag{4}$$

Even though FFT is a widespread method based on only the frequency spectra, not provide any detail according to the frequency and time synchronously [14].

b. Short-Time Fourier Transform (STFT): $M, L_{overlap}$, and R are window lengths of the time series, overlapped, and residual signals respectively in STFT. The last length of the time-frequency response of the STFT must be integer based on ¥ in Eq. (5) [15]. If ¥ is noninteger, a zero padding is applied into the time-series window and then removed from the STFT response.

$$¥ = \left\lfloor \frac{N_x - L_{overlap}}{M - L_{overlap}} \right\rfloor, \qquad N_x: Length\ of\ x \tag{5}$$

$X(f)_{[kx1]}$ encompasses mR time-centered DFT data:

$$X_m(f) = \sum_{n=-\infty}^{\infty} x(n) g(n - mR) e^{-j2\pi f n} \tag{6}$$

In order to obtain the time-frequency responses of the results, normalization must be carried out and this normalization is achieved by substitution of overlapping percentage, O. P. in Eq. (7) into Eq. (8).
N$_x$=1000, N$_{DFT}$==128, O.P.=0.75 are selected in this study.

$$\text{Overlapping percentage, O.P.} = \frac{L_{overlap}}{M} \tag{7}$$

$$Normalization = \frac{\mathrm{N}_x}{\mathrm{N}_{DFT} * (1 - O.P.)} \tag{8}$$

c. Continuous Wavelet Transform (CWT): CWT is done for the power signal as in Eq. (9).

$$W_s(a,b) = \int \frac{x(t)}{\sqrt{a}} \overline{\Psi(\frac{t-b}{a})}\, dt \tag{9}$$

Ψ, b, and a represent wavelet window, time-shifting, and scaling coefficient respectively [16].

d. Empirical Mode Decomposition (EMD): EMD arranges the time components of the signal by providing the time-series signal $x(t)$ splitting into Intrinsic Mode Functions (IMFs), $imf_k(t)$ and the residual value $res(t)$. Each decomposed IMF detects the event time characteristics individually in the original signal [17]. Summation of the IMFs and the residue can reconstruct the original time series signal $x(t)$ with Eq. (10).

$$x(t) = \sum_{k=1}^{n} imf_k(t) + res(t) \tag{10}$$

e. Hilbert Huang Transform (HHT): HHT based on $imf_k(t)$ of EMD, $H[imf_k(t)]$ can be formulated as,

$$H[imf_k(t)] = P \int_{-\infty}^{+\infty} \frac{imf_k(\tau)}{\pi(t-\tau)} d\tau \tag{11}$$

The rearrangement of this equation gives Eq. (12).

$$H(w,t) = Re\left(\sum_{k=1}^{n} a_k(t)\, e^{j\int w_k(t)dt}\right) \tag{12}$$

In this equation, $a_k(t)$ and $w_k(t)$ are the instantaneous amplitudes and frequencies of the IMFs of EMD, respectively [18], [19].

4. PROPOSED SIGNAL PROCESSING APPLICATION

The article presents a program with two main subprograms, as illustrated in Figure 3. The first subprogram is a user-defined interface that allows the user to input phase and time variability. The second subprogram consists of a predefined signal and subprogram parts that respond to this signal using various methods, including FFT, STFT, CWT, EMD, and HHT.

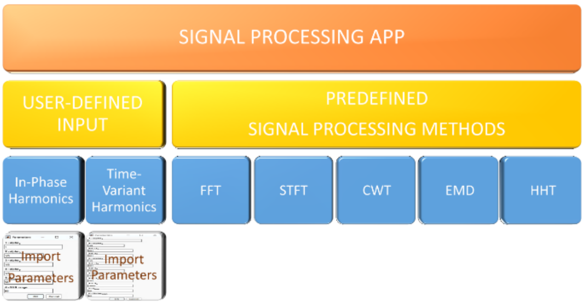


Figure 3. Block structure of the app.

The program uses default parameters, which are listed in Table 1. The user interface allows for changes to be made to the harmonic amplitude, frequency, and noise levels of these parameters. Further details on these sub-interfaces are discussed in the following sections.

Table 1. Default parameters of the systems.

Default Parameters of the systems	
Sampling Frequency (Hz)	$f_s = 5000$
Sampling period (sec)	$T = 1/f_s$
Length of signal	$L = 1000$
Window (Hz)	$win = L * T$
Resolution (sec)	$res = f_s/L$
Main Frequency (Hz)	$f_{line} = 50$
Harmonic Frequencies (Hz)	$f_3 = 150,\ f_5 = 250,\ f_7 = 350$
Harmonic Amplitudes (V_{pu})	$\alpha_3 = 1/3\ ,\ \alpha_5 = 1/5\ ,\ \alpha_7 = 1/7$
SNR Level (dB)	60

4.1.1. Input Option

The program presented allows for user login and predefined operations. The interface in Figure 4 offers the options of selecting User-Defined Input or Predefined Signal Processing Methods by selecting 1 or 2, respectively.

4.1.2. User- Defined Input

Choosing User-Defined provides a time range option for creating harmonic signals.

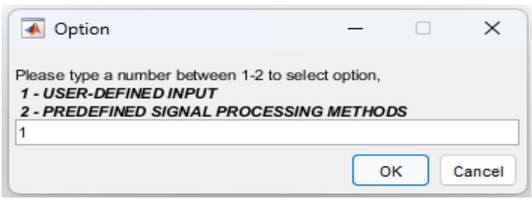


Figure 4. Input selection.

4.1.3. Time Range Option

When selecting user-defined input, two separate interfaces are available for in-phase or time-varying harmonic values. The sub-interface in Figure 5 shows the options for selecting these values.

4.1.3.1. In-Phase Harmonics

The interface for selecting the relevant parameters for in-phase harmonics is shown in Figure 6, and is based on signal model Eq. (2). The fundamental component's amplitude and frequency, as well as the amplitudes of the harmonics and the total noise's added noise level, are provided here.

4.1.3.2. Time-Variant Harmonics

The model for the time-variant harmonics signal Eq. (3) and the interface for selecting relevant parameters based on user input in Figure 7 are presented. The starting and ending points of the harmonics are also determined by Eq. (3), in addition to the variables in the in-phase component.

4.2. Predefined - Signal Processing Methods

The Predefined - Signal Processing Methods subprogram includes an interface, shown in Figure 8, for obtaining results that align with the method used to analyze the harmonic components created using default parameters. This allows for results to be obtained using five different methods: FFT, STFT, CWT, EMD, and HHT.

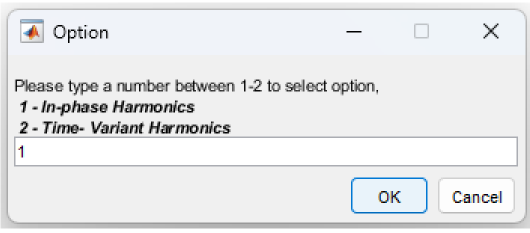


Figure 5. Time - Option selection.

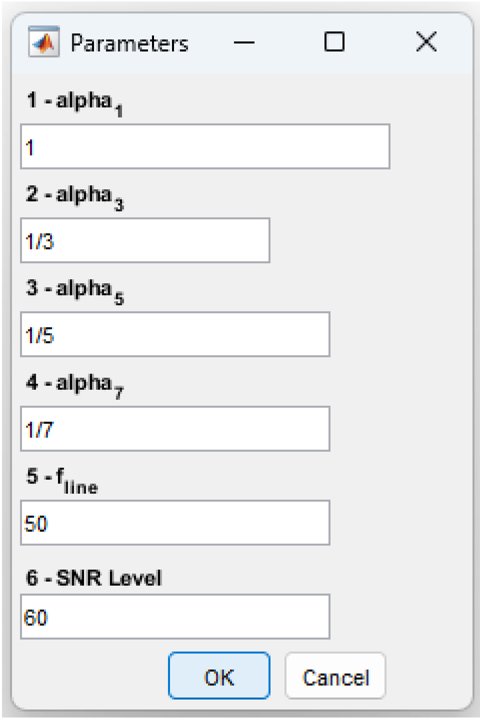


Figure 6. In-Phase harmonics input.

5. RESULTS AND DISCUSSION

The application presents five different options for the user to examine the responses of the methods against the default values in Figure 8: FFT, STFT, CWT, EMD, and HHT. The results obtained from the study were separated for user-defined and pre-defined signals.

a. For User-Defined Signals

The following section provides a detailed discussion of the results obtained for user-defined signals.

i. For In-Phase Harmonics

Firstly, the results for the signal with in-phase harmonics are presented. Figure 9 shows a comparison of the results obtained using the inputs given in Figure 6 for four different methods. The FFT method provides high resolution and accurately identifies the amplitudes of frequencies at 50, 150, 250, and 350 Hz, with a linear frequency change. STFT and CWT methods can generate similar results in exact frequency spectra where the resolution is low or nonlinear. The figure shows that component values around 50, 150, 250, and 350 Hz are separated in regions near the beginning and end, depending on the filter banks used in this method. Furthermore, it has been observed that

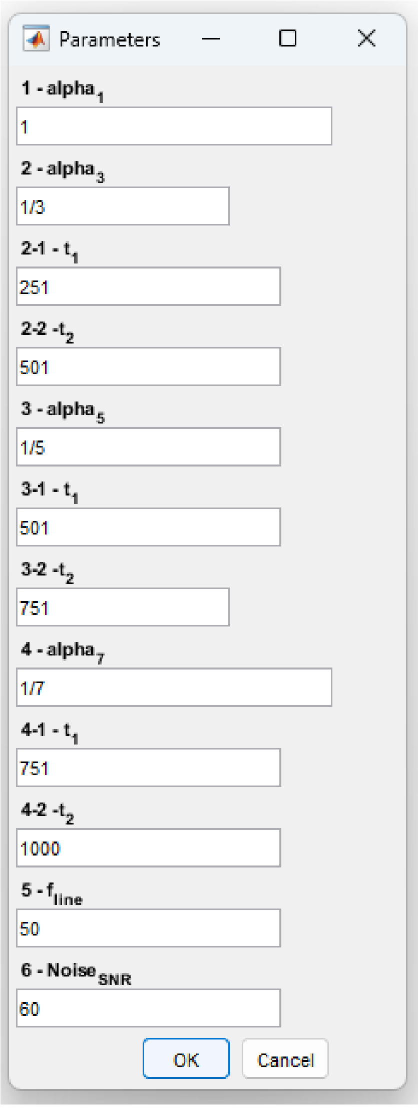


Figure 7. Time-Variant harmonics input.

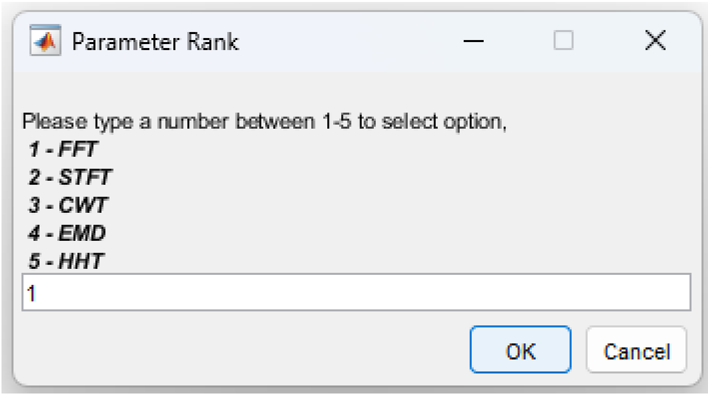


Figure 8. Selection of signal processing method for default values.

a component as high as 350 Hz, which is not an integer multiple, fluctuates over time depending on the sampling frequency. When using EMD results, HHT also has a nonlinear frequency spectrum space. The results may fluctuate depending on the IMFs, which are EMD components at each frequency point. Unlike FFT, which only produces results in the time domain and linear frequency, methods such as STFT, CWT, and HHT can provide answers in the time-frequency domain, but cannot give nonlinear and sharp answers.

ii. For Time-Variant Harmonics

The results of four different methods were compared for a signal with time-variant harmonics, as shown in Figure 10 using the inputs from Figure 10. The results obtained from FFT showed a significant decrease in harmonic amplitudes depending on the duty cycle ratio and the occurrence of harmonics at different time intervals. The fundamental component, which is the 50 Hz component, was fully obtained. The STFT results indicate that during the time period when the harmonics were individually effective, approximate results with decreased amplitude in the frequency spectrum were obtained. The use of CWT revealed that although there is some dispersion at the beginning and end of the event, the results are obtained more robustly in the nonlinear frequency spectrum, similar to in-phase harmonics. HHT also exhibits a non-linear frequency spectrum. Although events aredefined by their start and end points, their outcome frequencies fluctuate. The FFT analysis has shown that harmonic formations significantly affect the amplitude. STFT, CWT, and HHT all produce simultaneous results in the time-frequency domain, but the most robust results were obtained with CWT.

b. For Predefined - Signal Processing Methods

The results obtained using the default values given in Table 1 the signals used in the Predefined - Signal Processing Methods sub-interface, which is another approach, are discussed in detail below.

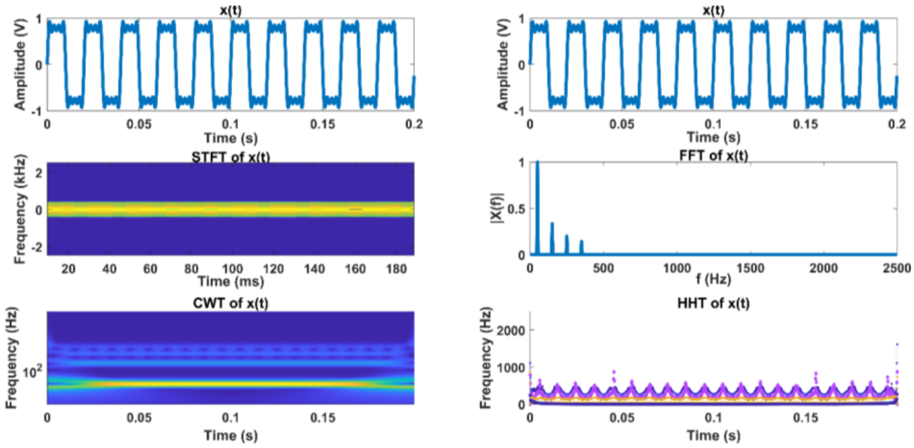


Figure 9. Comparative responses for in-phase harmonics.

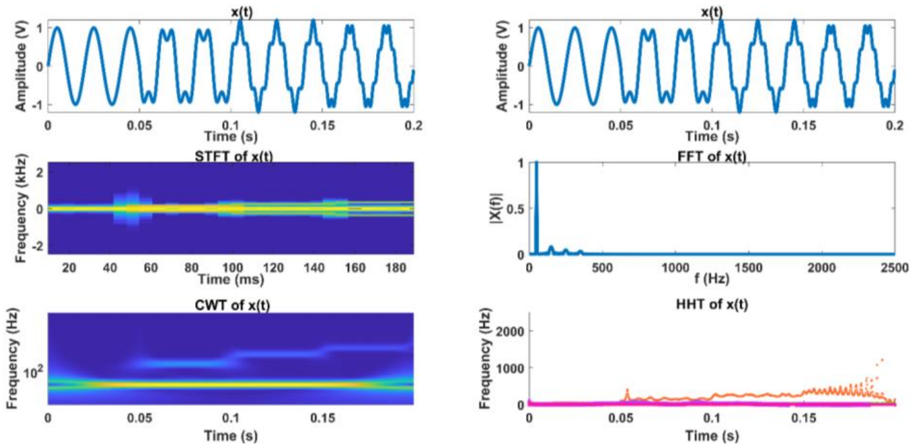


Figure 10. Comparative responses for time-variant harmonics.

i. **FFT**

The considered harmonic signal and the signal obtained by FFT rotation were obtained as shown in Figure 11. Table 2 gives the detailed results of this figure. It can be seen that the frequency and amplitude results obtained are free of error and the frequency spectrum is linear. It is also clear that the results obtained using this method only give results in the frequency spectrum. Therefore time-frequency is not suitable for simultaneous results.

ii. **STFT**

The relevant harmonic signal and the signal obtained by STFT transformation were obtained as seen in Figure 12. Detailed results for STFT are provided in Table 3. By that, it can be seen that the frequency spectrum is linear but its resolution is quite low, and accordingly, the frequency and amplitude results are obtained partially incorrectly. These errors are especially deviated at points where the measured values are incompatible with the resolution, such as the fundamental harmonic and 5th Harmonic frequencies. The values obtained here were obtained by normalizing the results according to the overlapping percentage and FFT transformation length. However, unlike FFT, it can be seen from the figure and the relevant table that time-frequency is suitable for simultaneous results. The fluctuation in frequency can be seen more clearly in the 3D image in Figure 12.c. Therefore, average values were obtained for the amplitudes.

Table 2. Different responses and features of the FFT.

	Main Component	Harmonic Components		
Inphase Time / Frequency information	Not available			
Frequency Deviation Robustness	Sensitive			
Sensitivity to Noise	Sensitive			
Frequency Resolution (Hz)	Linear: 5 Hz			
Nominal Amplitude (V_{pu})	1	1/3	1/5	1/7
Measured Amplitude (V_{pu})	1	0.33333	0.2	0.142857
Error (%)	**0**	**0**	**0**	**0**
Nominal Frequency (Hz)	50	150	250	350
Measured Frequency (Hz)	50	150	250	350
Error (%)	**0**	**0**	**0**	**0**

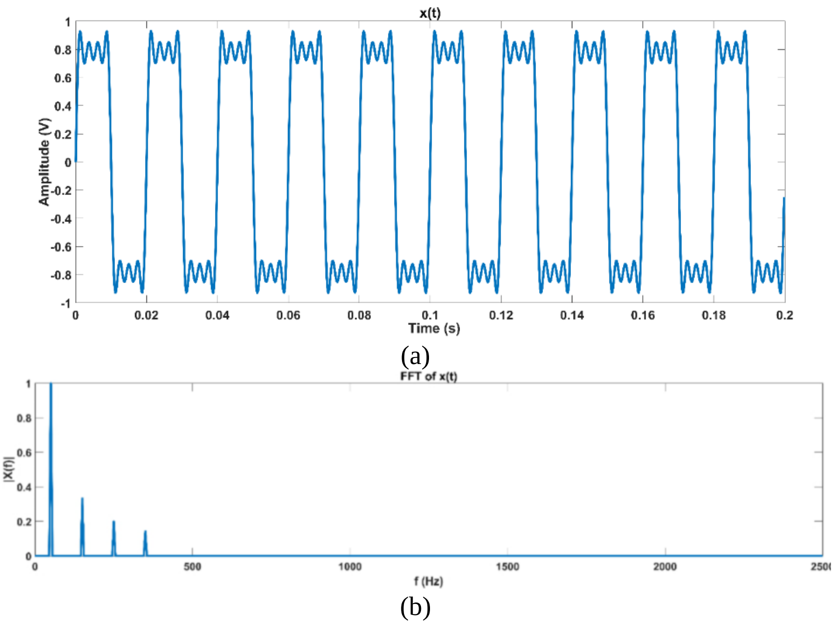


Figure 11. FFT response.

Table 3. Different responses and features of the STFT.

	Main Component	Harmonic Components		
Inphase Time / Frequency information	Available			
Frequency Deviation Robustness	Effective			
Sensitivity to Noise	Robust			
Frequency Resolution (Hz)	Linear: 39.0625			
Nominal Amplitude (V_{pu})	1	1/3	1/5	1/7
Measured Amplitude (V_{pu})	0.9756	0.3367	0.1850	0.1466
Error (%)	**-2.4400**	**1.0100**	**-7.5000**	**2.6200**
Nominal Frequency (Hz)	50	150	250	350
Measured Frequency (Hz)	39.0625	156.2500	234.3750	351.5625
Error (%)	**-21.8750**	**4.1667**	**-6.2500**	**-0.4464**

iii. CWT

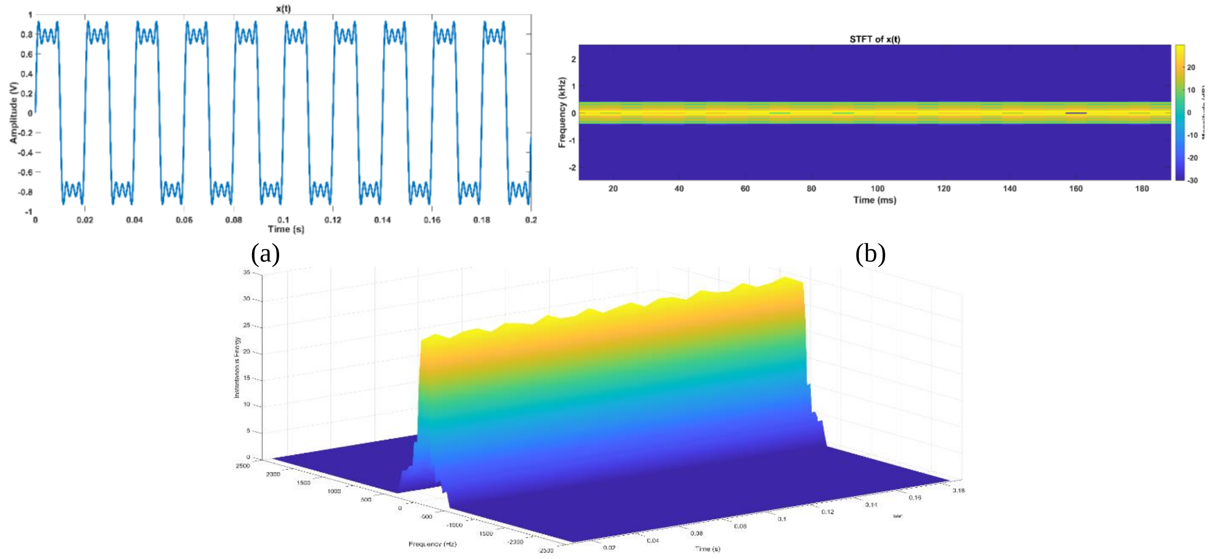
The resulting images obtained with the CWT transformation are shown in Figure 13. Results for CWT are stated in Amplitude values were obtained with very low errors compared to EMD. Although the components are difficult to distinguish in the 2D image, these effects are quite evident in the 3D results. In addition, the amplitude fluctuation is more apparent. Although being based on EMD makes the method sensitive to frequency deviation, it is effective in terms of time-frequency analysis and robustness to noise.

iv. EMD

Another approach is the EMD method, which separates each component into different frequency components simultaneously. The resulting images obtained by EMD transformation were obtained in 2 and 3 dimensions as shown in Figure 14. The IMF components obtained by EMD are obtained from the frequency components from the highest to the lowest, and the last one gives the residue. Detailed results of this visualization are given in Table 5. IMF2 and IMF3 belong to approximately 150 Hz and 50 Hz components respectively; it can be seen that IMF1 belongs to the 275 Hz component. In this case, the waveform and energy of the 250 Hz and 350 Hz components are seen together in the 275 Hz component. Therefore, Table 5 signifies that the frequencies and amplitudes of these components have high errors. The frequency resolution also varies non-linearly. As a result, although it issuitable for partially inphase time-frequency analysis, it is seen that it is not robust to frequency deviation and noise.

v. HHT

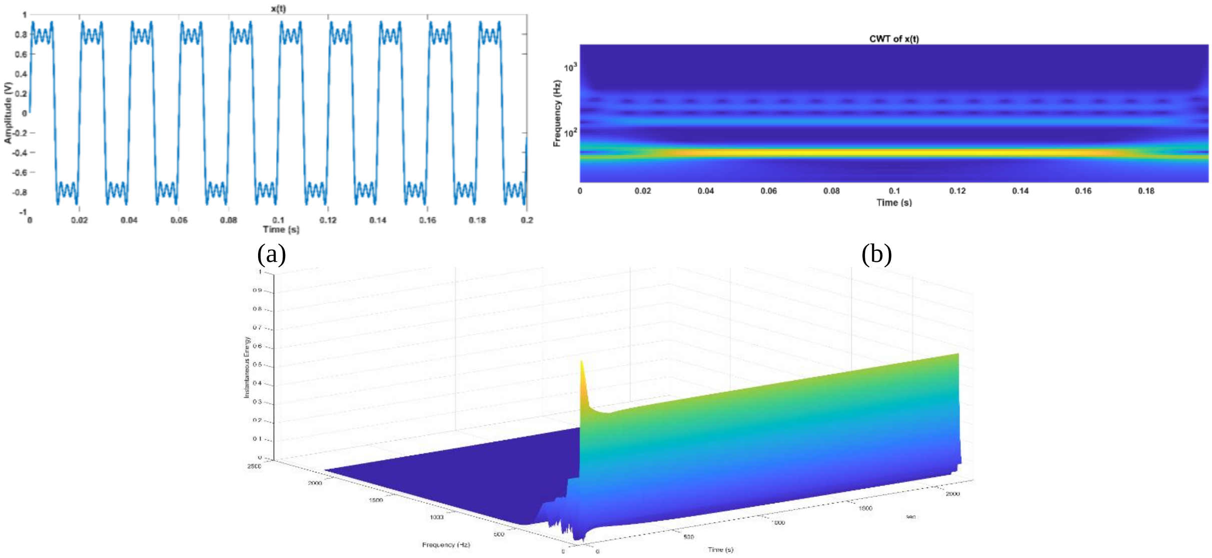
The final approach using the EMD responses as input is the HHT method. The result images obtained with this method were obtained in 2 and 3 dimensions, as shown in Figure 15. As shown in Table 6, the fact that the frequency resolution is linear and 25 Hz is an advantage in terms of obtaining the frequency components separately.



(a) (b)

(c)

Figure 12. STFT response.



(a) (b)

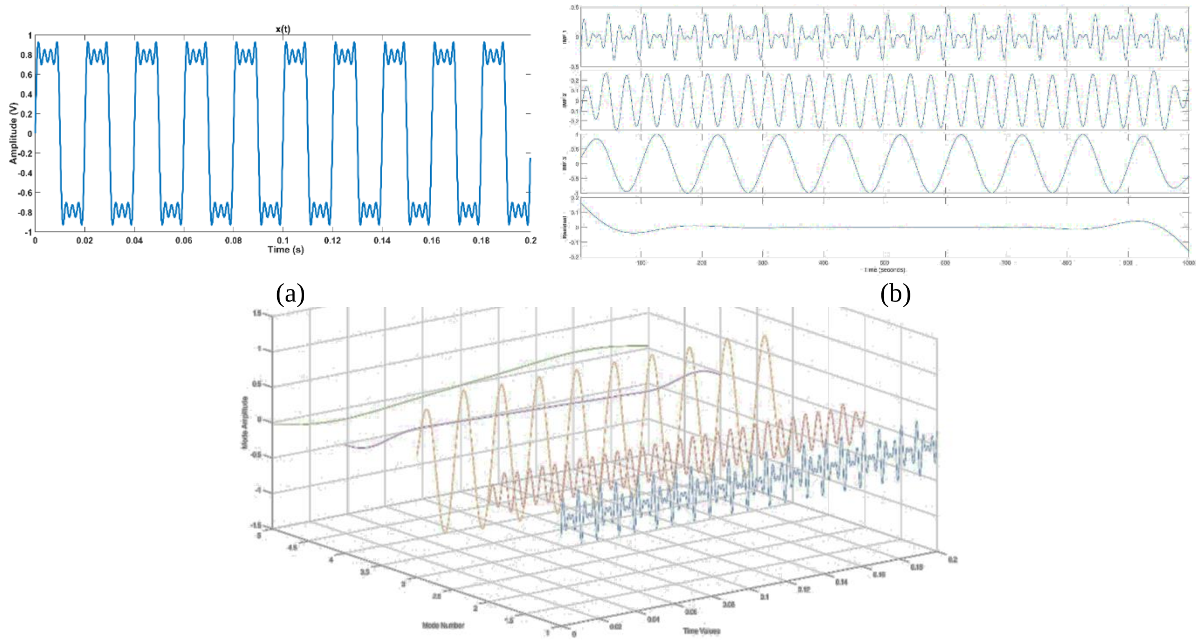
(c)

Figure 13. CWT response.

Table 4. Different responses and features of the CWT.

	Main Component	Harmonic Components		
Inphase Time / Frequency information	Available			
Frequency Deviation Robustness	Effective			
Sensitivity to Noise	Robust			
Frequency Resolution (Hz)	Nonlinear: 1.2171 … 145.3601			
Nominal Amplitude (V_{pu})	1	1/3	1/5	1/7
Measured Amplitude (V_{pu})	0.977738	0.323476	0.197581	0.128497
Error (%)	**2.22620**	**2.95720**	**1.20950**	**10.05210**
Nominal Frequency (Hz)	50	150	250	350
Measured Frequency (Hz)	51.4070	145.4010	253.1578	358.0192
Error (%)	**-2.81399**	**3.06599**	**-1.26312**	**-2.29120**

Amplitude values were obtained with very low errors compared to EMD. Although the components are difficult to distinguish in the 2D image, these effects are quite evident in the 3D results. In addition, the amplitude fluctuation is more apparent. Although being based on EMD makes the method sensitive to frequency deviation, it is effective in terms of time-frequency analysis and robustness to noise.



(a) (b)

(c)

Figure 14. EMD response.

Table 5. Different responses and features of the EMT.

	Main Component	Harmonic Components		
Inphase Time / Frequency information	Available (Partly)			
Frequency Deviation Robustness	Ineffective			
Sensitivity to Noise	In-Robust			
Frequency Resolution (Hz)	Nonlinear: 15.7140 - 125.8983			
Nominal Amplitude (V_{pu})	1	1/3	1/5	1/7
Measured Amplitude (V_{pu})	1.00963	0.29550	0.38748	-
Error (%)	-0.9630	11.3500	-93.7400	-
Nominal Frequency (Hz)	50	150	250	350
Measured Frequency (Hz)	50.6035	150.8265	276.7248	-
Error (%)	-1.20700	-0.55100	-10.6899	-

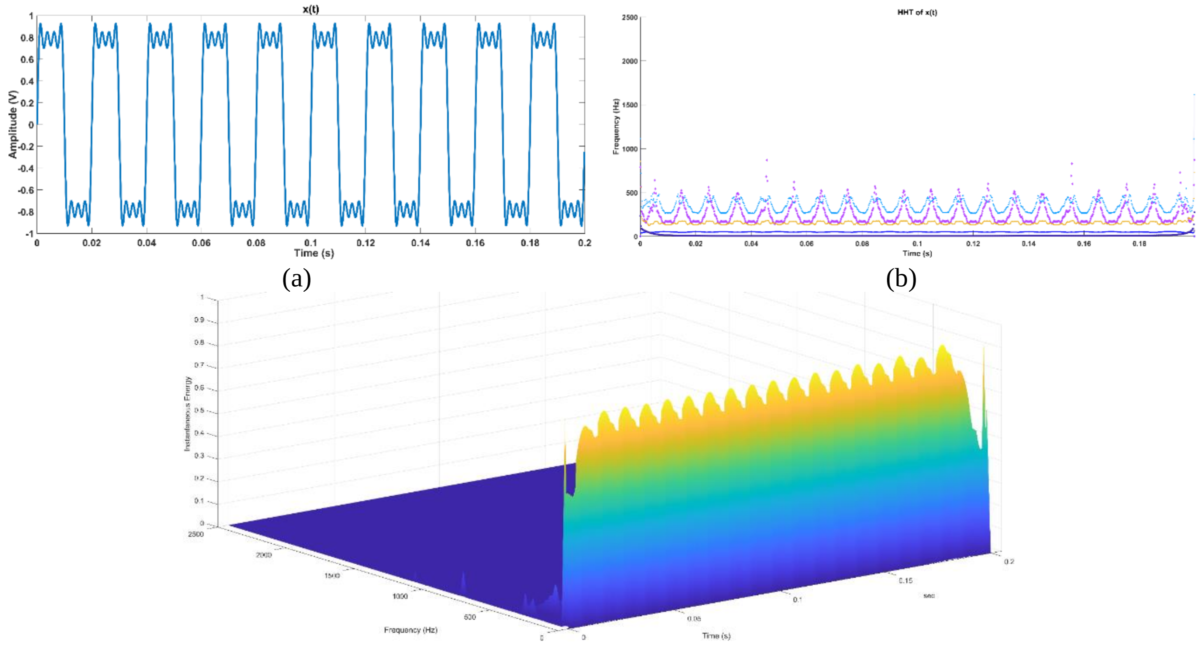
Table 6. Different responses and features of the HHT.

	Main Component	Harmonic Components		
Inphase Time / Frequency information	Available			
Frequency Deviation Robustness	Ineffective			
Sensitivity to Noise	Robust			
Frequency Resolution (Hz)	Linear: 25			
Nominal Amplitude (V_{pu})	1	1/3	1/5	1/7
Measured Amplitude (V_{pu})	0.946	0.0453	0.1365	0.0502
Error (%)	**2.22620**	**2.95720**	**1.20950**	**10.05210**
Nominal Frequency (Hz)	50	150	250	350
Measured Frequency (Hz)	50	150	250	350
Error (%)	**0**	**0**	**0**	**0**

6. CONCLUSION

With the study, an app that enables the synthesis and production of $3^{rd}, 5^{th},$ and 7^{th} harmonics, which are important disturbance effects for power systems, has been proposed. This app allows the production of harmonics that occur at different time intervals by determining the amplitude, noise, and event start-end times. CWT, EMD, and HHT. In addition, there is also a sub-interface for the user to analyze pre-defined data with the desired methods for easy use. In this way, it allows simultaneous analysis for domains of frequency and time-frequency. The performance of the responses obtained from the proposed signal processing methods in terms of various amplitude, frequency, and resolution parameters were examined and their advantages and disadvantages compared to each other were revealed. While high frequency, frequency, and amplitude results can be obtained with 0% error with FFT in an environment of 60 dB with a low noise level, an answer can only be obtained when the frequency is received. Other methods that can provide simultaneous results in the time-frequency domain have low resolution.

Due to the spread of frequency responses in the frequency domain, high errors occurred in the EMD frequency and amplitude results, which reduced 4 frequency components to 3.



(a) (b)

(c)

Figure 15. HHT response.

In addition, it has been observed that the HHT transformation, which uses EMD results, gives high accuracy results compared to other methods, with 0% error in frequency responses and error values between 2.22% and 10.05% in amplitude responses. By using these results, with the help of the presented app, syntheses and analyses for time and time-frequency domain responses can be made comparatively with the help of the signal processing methods discussed. There is a plan for the application presented here a detailed application that can respond to more degradation types in future studies.

Author Contributions

All stages of the study were done by the author.

Conflict of Interest

Author declares that he has no conflicts of interest.

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