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Analysis And Wave Visualization Of Electrical Circuits Using Fourier Series With Matlab

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Abstract

This research aimed to analyse and observe the visualization of waves from electric circuits using Fourier series with Matlab . This research used a literature study, where researchers learnt books and journals about the application of the Fourier series to solve electrical circuit cases and the operation of the Fourier series in Matlab to facilitate the analysis process and observe the visualization of waves. Fourier series calculation produced a voltage value (V) where high harmonic (n) caused low voltage. In addition, at the RMS voltage (V_{RMS}) value, a high harmonic (n) caused a low RMS voltage (V_{RMS}). In this research, researchers obtained a visualization of a sinusoidal wave where every odd number harmonic increased, the amplitude (A) and the wavelength (λ) were getting shorter. If the harmonic value was even then no wave was generated because the harmonics produced a voltage (V), frequency (f), and wavelength (λ) of zero value. So, it did not form a wave.
Keywords: Electrical circuits; Fourier Series; Matlab; Wave

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Introduction:

Physics is a science that studies the motion and properties of non-living objects in nature (Kaniawati, 2017). Physics is one of the basic sciences as the basis for the development of science and technology (Malik et al., 2018). The function and purpose of physics subjects is to develop inductive and deductive analytical thinking skills using the concepts and principles of physics. It aims to explain nature phenomenon and solve various problems quantitatively and qualitatively (Bain et al., 2014; Liliarti, 2018). Physics is also one of the subjects that are difficult to understand for some people, especially Indonesia students. This is because of the combination of numbers and complex formulas as well as complex concepts so some students are not interested in exploring the subject. One of the tools to solve physics problems is mathematics.

Mathematics as a tool is a science of logic regarding shapes, orders, quantities and concepts that are interconnected with large numbers and divided into three fields, namely geometry, algebra, and analysis (Suherman, 2001). Mathematics interprets physical objects in the form of equations. These equations support to understand natural phenomena. One of the mathematical materials used to produce equations for natural phenomena is the Fourier series.

The Fourier series is an infinite series with terms containing sine-cosine and trigonometric components that converge on a periodic function (Soedijono, 2016). Fourier series is a series to simplify complex wavefunctions containing cosine and sine. This series also serves to simplify the magnitude of periodic waves or a continuous waves for a certain time (Sandi & Malinda, 2015).

One of the physics materials related to periodic waves is an electric circuit. Based on the electricity flow, electric current is divided into 2 (two) categories, namely direct current/DC and alternating current/AC.

Direct current/DC and alternating current/AC have different waveforms. The direct current/DC wave does not change, and its polarity remains at the positive and negative poles. While the alternating current/AC wave goes up and down because it depends on the frequency. Matlab is used to make it easier to see the waveforms of direct current (DC) and alternating electric current (AC).

Matrix Laboratory (MatLab) is a unique collection of modern computer mathematical numerical methods implementations over the last three decades (Kurasov, 2020). Matrix Laboratory (MatLab) is software to calculate and analyse numerical, linear algebraic studies, and matrix theory (Hong & Cai, 2010; Learning & Kim, 2017). Matrix Laboratory (MatLab) is also a calculator with complete facilities (Utari et al., 2021). In addition, Matrix Laboratory (MatLab) is a computer program that utilizes the matrix base. Matlab uses a simple matrix, so it is easy to use (Atina, 2019). Matlab is useful for analysing easy to difficult mathematical calculations. Matlab is very useful nowadays. In addition, matlab can also visualize invisible objects that are only represented using mathematics, such as electric current waves.

METHODS

Research objective

This research aimed to analyse and visualize the waveform of an alternating current (AC) electric circuit using Fourier series with Matlab.

Research methods

This research method was literature study, which is a method that studies books and journals (Zed, 2008). Books and journals were the application of Fourier series to interpret, analyse and visualize electrical circuits using mathlab.

RESULTS AND DISCUSSION

The results were as follows:

1. Alternating Current (AC)

Electric current is divided into two, namely direct current or called DC and alternating current or AC. This research discussed the analysis and visualization of the waveform of an alternating current (AC) electric circuit. Alternating current (AC) is the electrons flow from a higher electric potential energy to a lower potential energy. AC characteristics include: 1) The value of electric current is always changing or not constant with time; 2) The polarity of each terminal varies and 3) The waveform I (current) on t (time) or V (voltage) on t (time) is sinusoidal, where the values of V and I are not constant with time (Gideon & Saragih, 2019).

2. Fourier Series

Fourier series general equation form (Mary L. Boas, 2006) :

$$f(x) = \frac{a_0}{2} + \sum_{1}^{\infty}(a_n \cos\frac{n\pi x}{l} + b_n \sin\frac{n\pi x}{l})$$

Where:

$$a_0 = \frac{1}{l}\int_{-l}^{l} f(x)dx$$

$$a_n = \frac{1}{l}\int_{-l}^{l} f(x)\cos\frac{n\pi x}{l}\,dx$$

$$b_n = \frac{1}{l}\int_{-l}^{l} f(x)\sin\frac{n\pi x}{l}\,dx$$

$$b_n = \frac{1}{l}\int_{-l}^{l} f(x)\sin\frac{n\pi x}{l}\,dx$$

The general form of the sine series half range:

$$a_n = 0, b_n = \frac{2}{l}\int_{0}^{l} f(x)\sin\frac{n\pi x}{l}\,dx$$

The general form of the cosine series half range:

$$b_n = 0, a_n = \frac{2}{l}\int_{0}^{l} f(x)\cos\frac{n\pi x}{l}\,dx$$

The general form of a Fourier series with arbitrary periodicity:

$$f(t) = a_0 + \sum_{n=1}^{\infty} a_n \sin\left(\frac{2n\pi t}{T}\right) + \sum_{n=1}^{\infty} b_n \cos\left(\frac{2n\pi t}{T}\right)$$

Where :

$$a_0 = \frac{1}{T}\int_{-T}^{T} f(t)dt$$

$$a_n = \frac{1}{T}\int_{-T}^{T} f(t)\cos\left(\frac{2n\pi t}{T}\right)dt$$

$$b_n = \frac{1}{T}\int_{-T}^{T} f(t)\sin\left(\frac{2n\pi t}{T}\right)dt$$

The general equation for the wave magnitude

$$f = \frac{1}{T}$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$\theta = \omega t$$

3. Case study

AC Electrical Circuit
The analysis and observation of AC electrical circuit waves from several conditions were as follows.

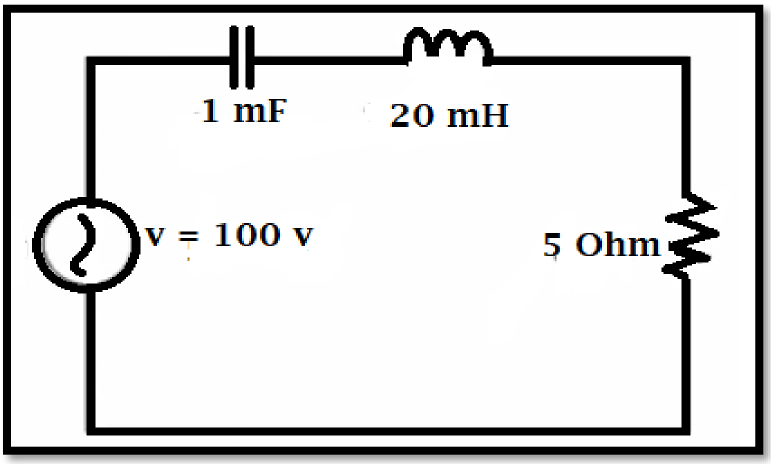


Figure 1. An example of an alternating circuit (AC).

The example above determines the voltage and waveform visualization. The equation of the above circuit was

$$v(t) = \begin{cases} 100 & 0 < t < 0{,}01 \\ 0 & 0{,}01 < t < 0{,}02 \end{cases}$$

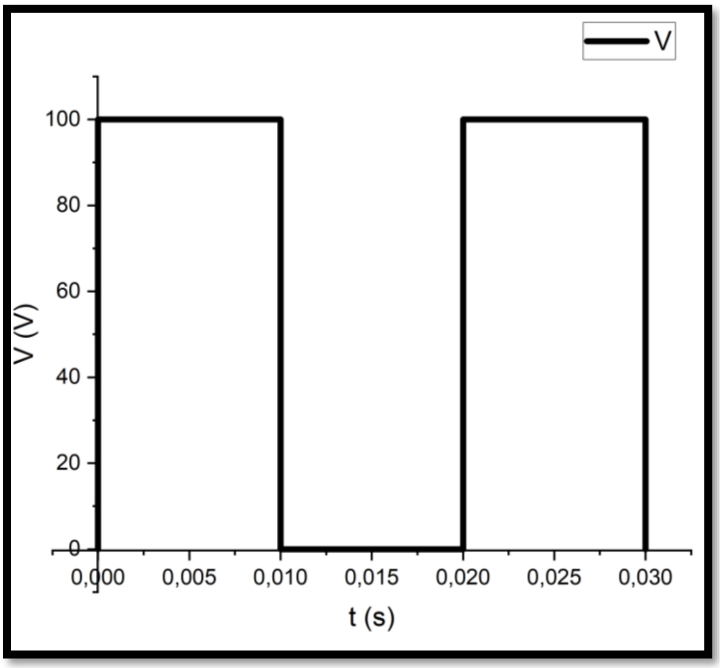


Figure 2. Graph (V) toward t(s) about the electrical circuit in Figure 1.

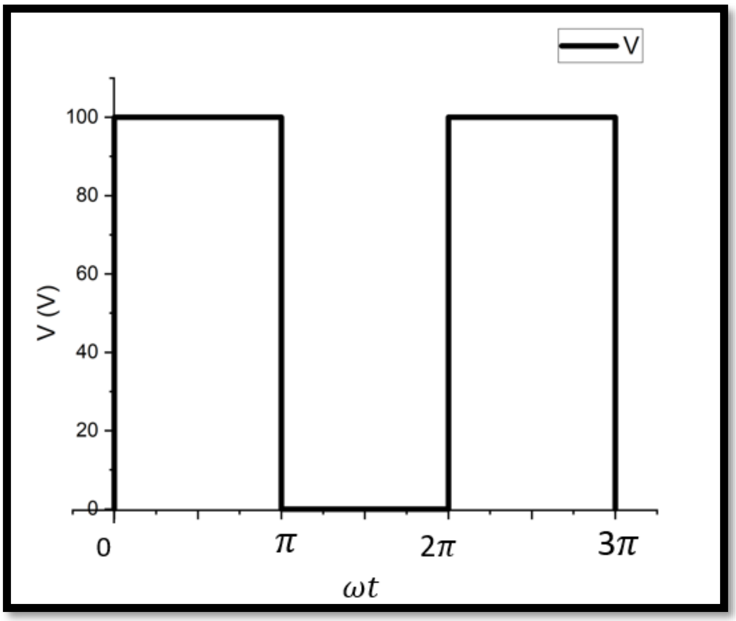


Figure 3. The graph (V) toward (ωt) of the electrical circuit in Figure 1.

$$v(\omega t) = \begin{cases} 100 & 0 < \omega t < \pi \\ 0 & \pi < t < 2\pi \end{cases}$$

$$v(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} (a_n \cos(n\omega t) + b_n \sin(n\omega t))$$

$$a_n = \frac{2}{T}\int_0^T v(\omega t) \cos(n\omega t)\, d(\omega t)$$

$$a_n = \frac{2}{T}\int_0^T v(\omega t)\cos(n\omega t)\, d(\omega t)$$

$$b_n = \frac{2}{T}\int_0^T v(\omega t)\sin(n\omega t)\, d(\omega t)$$

Or it could be simplified,

$$v(\omega t) = V_0 + \sum_{n=1}^{\infty}(V_n + \cos(n\omega t - \theta_n))$$

$$V_0 = \frac{a_0}{2}$$

$$V_0\cos(\mathrm{n\omega t} - \theta_n) = a_n\cos(\mathrm{n\omega t}) + b_n\sin\,(\mathrm{n\omega t})$$

$$V_n = \sqrt{a_n^2 + b_n^2} \qquad\qquad \theta_n = \tan^{-1}\left(\frac{b_n}{a_n}\right)$$

Looking for a_0

$$a_n = \frac{2}{T}\int_0^T v(\omega t)\cos(n\omega t)\, d(\omega t)$$

$$a_0 = \frac{2}{2\pi}\int_0^{2\pi} v(\omega t)\cos(0\mathrm{\omega t})\,\mathrm{d(\omega t)} = \frac{2}{2\pi}\int_0^{2\pi} v(\omega t)\mathrm{d(\omega t)}$$

$$a_0 = \frac{1}{\pi}\left[\int_0^{\pi} 100 d(\omega t) + \int_{\pi}^{2\pi} 0\, d(\omega t)\right]$$

$$a_0 = \frac{100}{\pi}\left[(\omega t)\,\Big|_0^{\pi}\right] = \frac{100}{\pi}[\pi - 0] = 100$$

$$\frac{a_0}{2} = 50$$

Looking for a_n

$$a_n = \frac{2}{T}\int_0^T v(\omega t)\cos(n\omega t)\, d(\omega t)$$

$$a_n = \frac{2}{2\pi}\left[\int_0^{\pi} 100\cos(\mathrm{n\omega t})\,\mathrm{d(\omega t)} + \int_{\pi}^{2\pi} 0\cos(\mathrm{n\omega t})\,\mathrm{d(\omega t)}\right]$$

$$a_n = \frac{100}{\pi}\left[\int_0^{\pi}\cos(\mathrm{n\omega t})d(\omega t)\right] = \frac{100}{2\pi}\left[\frac{\sin\,(\mathrm{n\omega t})}{n}\Big|_0^{\pi}\right] = \frac{100}{2\pi n}\left[\sin\,(\mathrm{n\omega t})\,\Big|_0^{\pi}\right]$$

$$a_n = 0$$

Looking for b_n

$$b_n = \frac{2}{T}\int_0^T v(\omega t)\sin(n\omega t)\, d(\omega t)$$

$$b_n = \frac{2}{2\pi}\left[\int_0^{\pi} 100\sin(n\omega t)\, d(\omega t) + \int_{\pi}^{2\pi} 0\sin(n\omega t) d(\omega t)\right]$$

$$b_n = \frac{2}{2\pi}\left[\int_0^{\pi} 100\sin(n\omega t)\, d(\omega t) + \int_{\pi}^{2\pi} 0\sin(n\omega t) d(\omega t)\right] b_n$$

$$= \frac{100}{\pi}\left[\int_0^{\pi} \sin(n\omega t)\, d(\omega t)\right] = \frac{100}{\pi}\left[\frac{-\cos(n\omega t)}{n}\Big|_0^{\pi}\right] = \frac{100}{\pi n}\left[-\cos\,(n\omega t)_0^{\pi}\right]$$

$$b_n = \frac{100}{\pi n}[-\cos(n\pi) - (-\cos(0))] = \frac{100}{\pi n}[-\cos(n\pi) + 1]$$

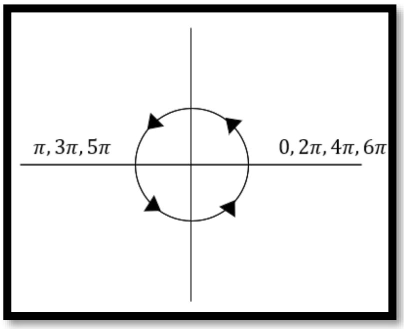


Figure 4. Cartesian nπ

$$[-\cos\,(n\pi) + 1] = 2 \qquad n = 1, 3, 5, \ldots.$$

$$[-\cos\,(n\pi) + 1] = 0 \qquad n = 2, 4, 6, \ldots.$$

$$b_n = \frac{200}{\pi n} \qquad n = 1, 3, 5, \ldots.$$

The fourier series equation of this wave was:

$$v(\omega t) = 50 + \sum_{n=1}^{\infty}(b_n \sin(n\omega t))$$

With

$b_n = \frac{200}{\pi n} \qquad n = 1, 3, 5, \ldots.$

$$v(\omega t) = 50 + \sum_{n=1}^{\infty}(V_n + \cos(n\omega t - \theta_n))$$

Where

$V_n = \sqrt{a_n^2 + b_n^2} = b_n$

$\theta_n = tan^{-1}\left(\frac{b_n}{a_n}\right) = 90°$

Table 1: *The analysis results of electrical circuits using the Fourier series*

Harmonic (n)	a_n	b_n	V_n	θ
1	0	63,66	63,66 V	90°
3	0	21,22	21,22 V	90°
5	0	12,73	12,73 V	90°
7	0	9,1	9,1 V	90°
9	0	7,07	7,07 V	90°
11	0	5,79	5,79 V	90°

Calculating the $V_{n(rms)}$ value and Frequency

$$V_{n(rms)} = \frac{V_n}{\sqrt{2}}$$

While the frequency value was formulated by:

$$f_n = n \times f_1\ (fundamental\ frequency)$$

Then, the $V_{n(rms)}$ value and harmonic frequency of 1, 3, 5, 7, 9 & 11 were as follows

Table 2: *Calculation results of $V_{n(rms)}$ value and Frequency*

Harmonic (n)	V_n	$V_{n(rms)}$	Frequency
1	63,66 V	45,01 V	50 Hz
3	21,22 V	15 V	150 Hz
5	12,73 V	9 V	250 Hz
7	9,1 V	6,43 V	350 Hz
9	7,07 V	5 V	450 Hz
11	5,79 V	4,09 V	550 Hz

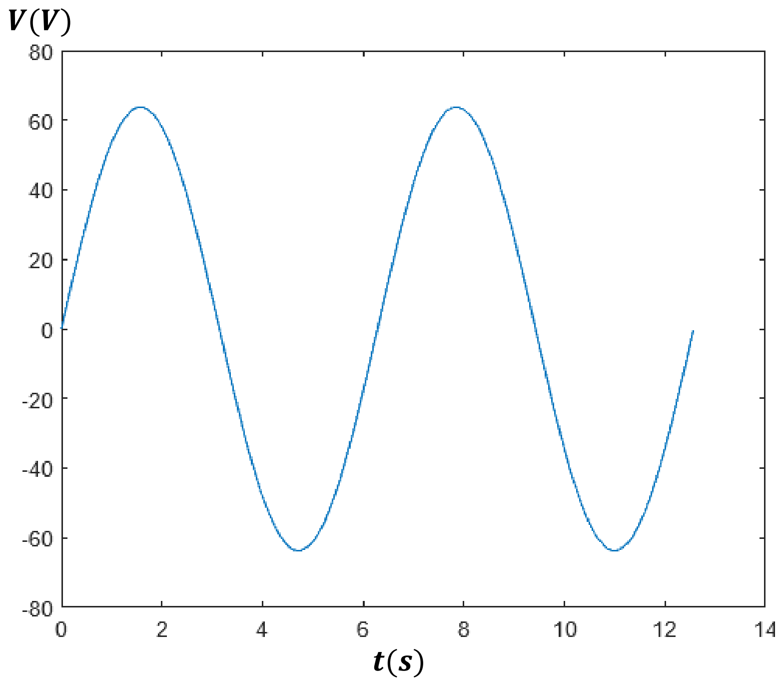
4. Visualization of Electrical Circuit Waves Using MATLAB.

The waveform display of each harmonic (n) was generated using the matlab program. The command to display the harmonic waveform of an electrical circuit in matlab was the plot command (Reri Afrianita & Laksono, 2015). Before the researchers wrote the plot command in the matlab work window, the researchers wrote the algorithms. The algorithm was as follows.

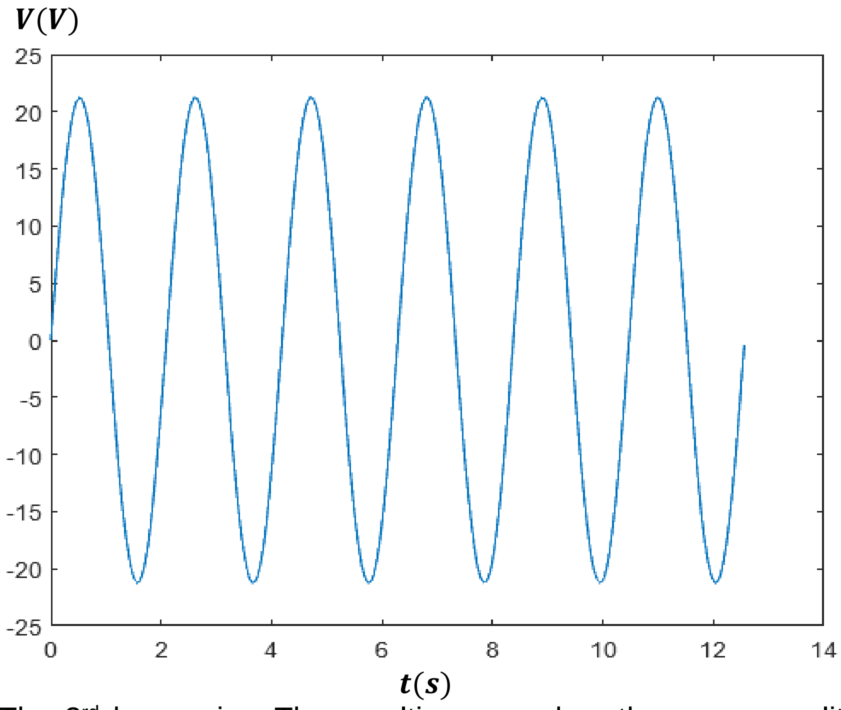
```
clear all
syms wt
n = 11;

f_1 = 100;
f_2 = 0 ;

an = 2/(2*pi) * (int(f_1 * cos(n*wt), 0, pi) + int(f_2 * cos(n*wt), pi, 2*pi))
bn = 2/(2*pi) * (int(f_1 * sin(n*wt), 0, pi) + int(f_2 * sin(n*wt), pi, 2*pi))

vn = sqrt(an^2 + bn^2)
teta = atan(bn/an)

wt = 0:0.01:4*pi ;
fn = vn * cos(n*wt - teta)
plot(wt,fn)
```

Figure 5. Algorithm for visualizing waves in electric circuits with Fourier series using Matlab.

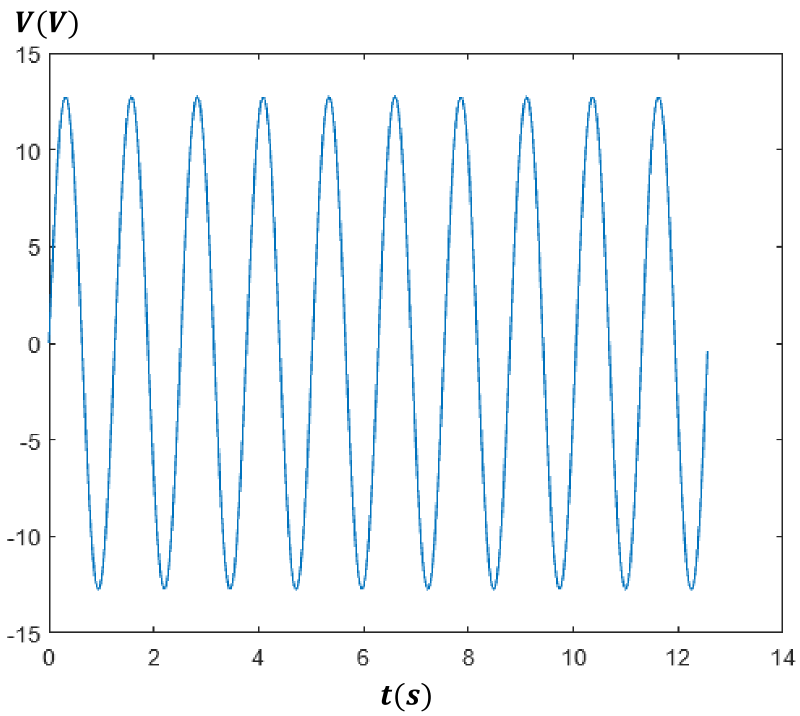
The waveform of each harmonic was displayed by inputing the harmonic value (n) alternately. This research observed at the value of odd (n) harmonics (n = 1, 3, 5, 7, 9 & 11) using a Fourier series where the b_n value for even harmonics is zero so no waves were generated.



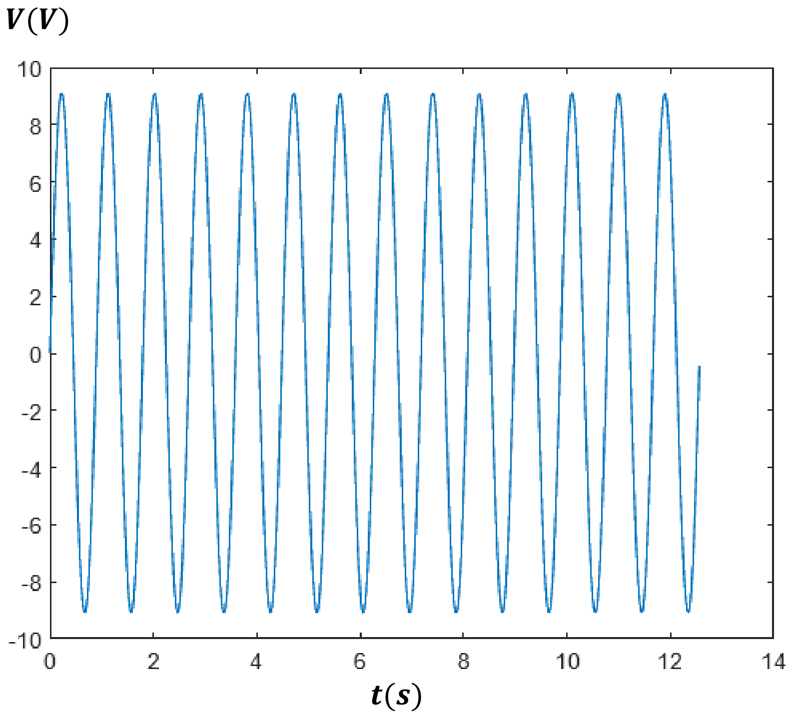
The 1st harmonic : The resulting wave has the same amplitude value as the voltage value, which is 63.66 in meters and produces 1.5$\boldsymbol{\lambda}$ in $\pm$13 seconds.



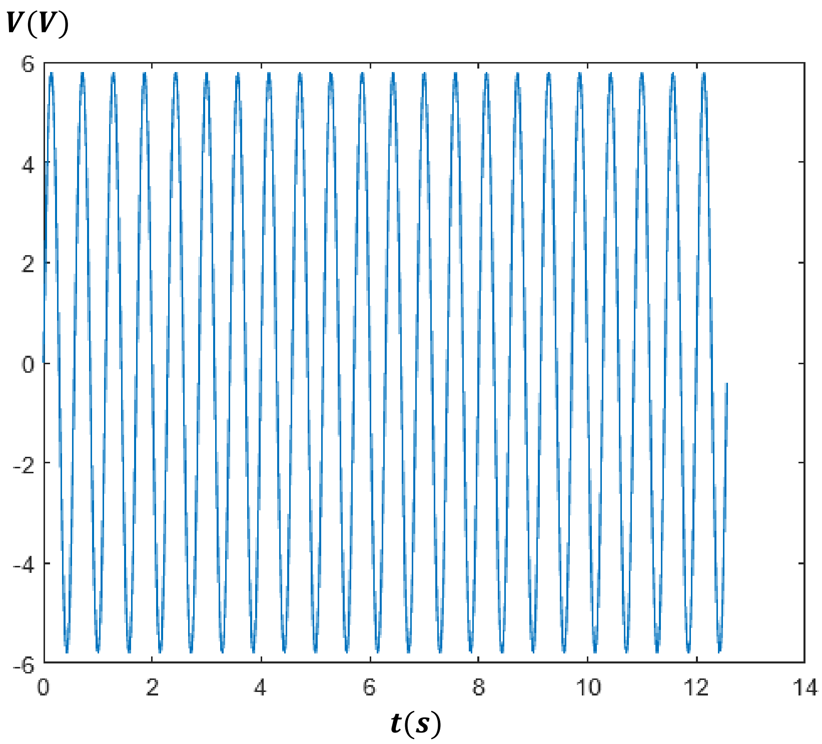
The 3rd harmonic : The resulting wave has the same amplitude value as the voltage value, which is 21.22 in meters and produces 5.5$\boldsymbol{\lambda}$ in $\pm$13 seconds.



The 5th harmonic : The resulting wave has the same amplitude value as the voltage value, which is 12.73 in meters and produces 9.5$\boldsymbol{\lambda}$ in $\pm$13 seconds.



The 7th harmonic : The resulting wave has the same amplitude value as the voltage value, which is 9.1 in meters and produces 13.5$\boldsymbol{\lambda}$ in $\pm$13 seconds.



The 11th harmonic : The resulting wave has the same amplitude value as the voltage value, which is 5.79 in meters and produces 21.5$\boldsymbol{\lambda}$ in $\pm$13 seconds.

Figure 6. Wave vis visualization in odd harmonic electric circuit (1, 3, 5, 7, 9, 11).

The case study explained that the Fourier series could analyze electrical circuits. The findings of the electrical circuit using the Fourier series were the voltage value (V) of each odd-value harmonic resulting in a high harmonic voltage. It caused low voltage. If the harmonic value was even, then the voltage was zero or there was no voltage. Next, the RMS voltage value (V_{RMS}) was sought by dividing the voltage value by the square root of two. The results of the RMS voltage (V_{RMS})) were high harmonics so the RMS voltage value (V_{RMS}) was low.

Equations and data analysis of electrical circuits using the Fourier series were also used to display the waveform visualization. Matlab program was used to view the waveform visualization of electrical circuits. Wave visualization showed that odd harmonic waves produced sinusoidal waves, which were repetitive waveforms. If the waves of each harmonic were compared, then the odd-value harmonics produced a small amplitude (A) and wavelength (λ). If the harmonic value was even then no wave was generated because the voltage (V), frequency (f) and wavelength (λ) were zero.

CONCLUSION

The Fourier series can analyze electrical circuits to generate rms voltage and voltage data where odd harmonics are large, then the voltage (V) and RMS voltage (V_{RMS}) are small, and if the harmonics are even, the voltage (V) is zero.

The Matlab program also displays a waveform visualization of an electrical circuit. Visualization of electrical circuits shows that large harmonics cause small amplitude (A) and wavelength (λ).

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