Visualization of Rectified Sine Waves and Triggering Angles on Thyristor Using Geogebra

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Abstract. GeoGebra is a tool that is widely used among academics to solve mathematical problems. GeoGebra can be visually generated in the form of graphs and computational results easily and quickly. In the field of electronic power, there is a problem with directed waves and waves triggered by a certain angle on the device thyristor. This paper will be discussed about visualization of rectified sine waveforms, triggering angles as well as integral values of directional waves in thyristor and three-phase source animation. With the GeoGebra tool, students can understand mathematical equations and make wave visualization on electronic power.

INTRODUCTION

Visualization is a way to visually show an event or equation. Visual appearance can make it easier to understand something. Mathematical equations use symbols that are often difficult for students to understand. To help students understand mathematical equations, visualization is required. GeoGebra is a web-based tool for geometry issues or other mathematical problems that are expected to help students in learning materials related to mathematics. Power electronics is one of the courses in electrical engineering related to voltage sources, rectifiers, and electric motors. Power Electronics talks about sine wave sources or signals, looking for average voltage, effective voltage, voltage rectifier, ripple voltage, different phases on three-phase sources.

GeoGebra is a web-based tool and application related to graphing, Geometry, 3D, and more. Through this tool makes it easy for users to create charts, users can try to change the parameters to instantly see the changes that occur, perform calculations directly. Paper articles related to GeoGebra include: Geometry Learning using GeoGebra (Dian, 2015), GeoGebra in Mechanical Engineering (Diyan, 2018), Interactive Physics Simulation (Tom, 2017), GeoGebra on Polygon material (Miftah, 2018), GeoGebra in mechanism (Iriante, 2014), GeoGebra in Transistor Amplifier (Zamora, 2020), Exploring Polar Curves with GeoGebra (Tuyetdong, 2012)

The problem faced is how to create visualizations (images, animations) to show mathematical equations in the field of power electronics using GeoGebra. The novelty of this study is that GeoGebra as a mathematical tool is applied in the field of power electronics to describe one-phase and three-phase voltage sources, rectified voltages, one-phase, and three-phase sine wave motion animations. Rotating field on an electric motor, calculation of RMS voltage and DC voltage

METHODS

The visualization that will be discussed is the sine wave before rectified and after rectified for one phase and three phases. Dynamic sine visualization (animation) and representation in phasor form. Trigger angle visualization for SCR and Thyristor rectifiers. Visualization of rotating fields on electric motors. Visualization results in the form of graphics, animations, and construction protocols (how to arrange, step steps on GeoGebra). The result of the graphic compared to the textbook, whether it matches.

Diode Rectifer, SCR, Thyristor

Diodes are electronic components that function to rectify AC voltage into DC voltage. A diode has two terminals namely anode and cathode. The diode becomes connected when it gets a forward bias voltage (Anode voltage is more positive compared to the cathode voltage) as shown in figure 1a. Diodes are disconnected (OFF) when they get a refractive voltage. Anode voltage is lower compared to cathode voltage. Diodes have a minimum voltage to become ON i.e. Vdiodes of 0.7V to simplify the use of ideal Diodes.

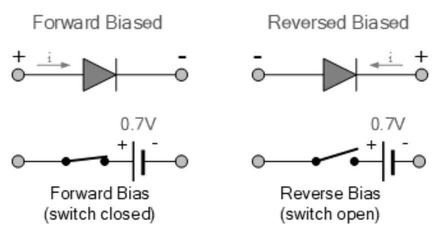


Figure 3. *a) diode in ON condition b) diode in OFF condition*

Mathematical equations for the rectifier diode as shown in Eq.1

$$Vout = \begin{cases} ON, & V_{anode} > V_{cathode} \\ OFF, & V_{ande} < V_{cathode} \end{cases} \quad (1)$$

SCR (Silicon Controlled Rectifier) is a diode-like component that has a Gate terminal pin as shown in figure 2. SCR works for semi-wave rectifiers (positive parts only) and is used on AC dimmers (light dimmers, motor speed slowing)

A thyristor is a 2-SCRs component that is mounted anti-parallel as shown in Fig.3. Thyristor also named Triac has 3 pins namely MT1, MT2, and gate. A thyristor is used as a full-wave rectifier that can be controlled when it becomes ON through the triggering angle of the sinus wave.

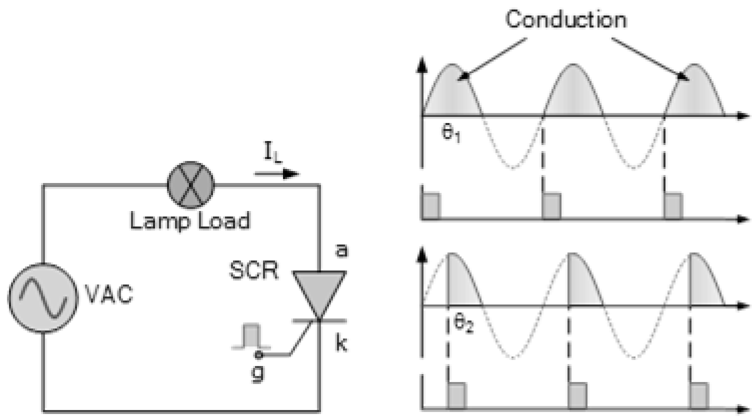


FIGURE 4. *trigger angle on SCR*

SCR can be ON when the Gate pin is activated and anode voltage is higher than cathode voltage.

$$SCR = \begin{cases} ON, & Va > V_k, \quad Vg = \delta(t-\theta) \\ OFF, & V_a < V_k \end{cases} \tag{2}$$

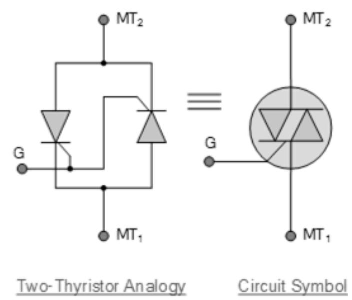
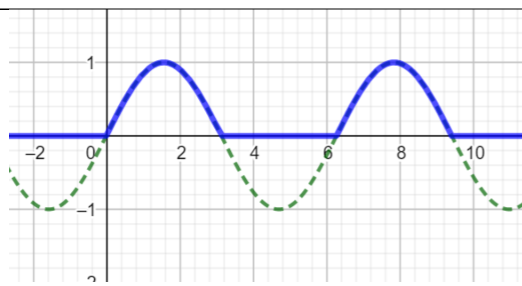
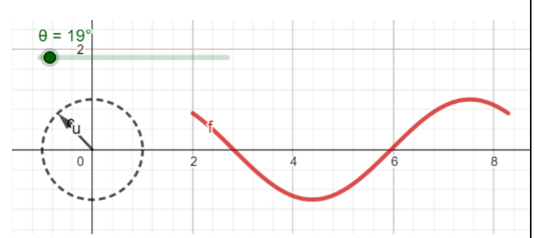


FIGURE 5. *Thyristor symbol and equivalence to SCR*

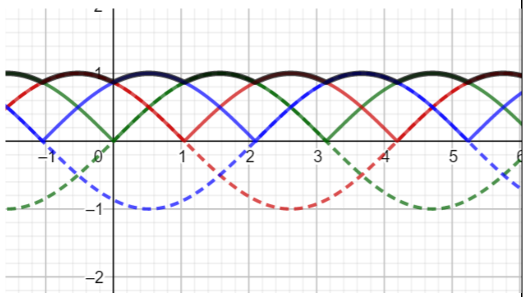
RESULTS AND DISCUSSION



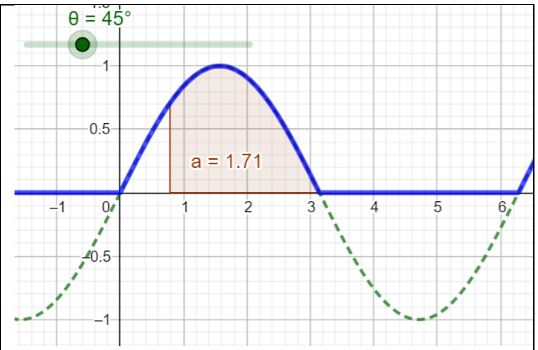
(a) half-wave rectified single sine wave



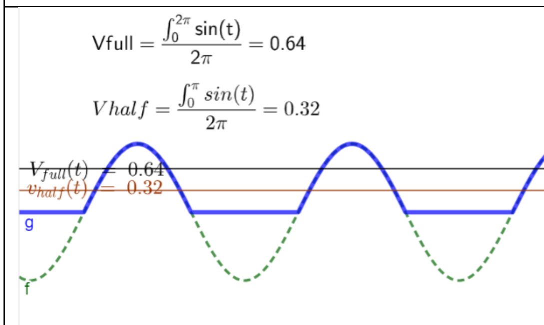
(b) Animated phasor and single sine wave



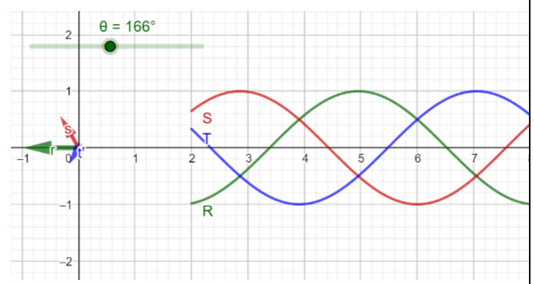
(c) Full-wave rectified three-phase sine wave



(d) Calculation of integral from delayed trigger sine wave on SCR



(e) Calculation of half rectified and full rectified sine wave with formula text



(f) Animation rotating field for three-phase sine wave

FIGURE 6. *visualize various graphics using GeoGebra*

The equation for the sine function is shown in equation (3)

$$f(t) = A\,sin(2\pi f\ t + \theta) \quad (3)$$

The equation for the half-wave rectified sine wave is shown in equation (4) and Fig.4(a)

$$f(t) = A\,|sin(2\pi f\ t + \theta)| \quad (4)$$

In figure 4. (b) Visualization can be an animation of a moving sine wave. The Construction Protocol for creating sine wave animations is shown in Fig.5. The sine graph that moves $f(t) = sin(t + \theta)$ with the value θ repeat value increase from 0 to 360°, normal speed of 1. The change in the speed of movement is determined by the speed on the slider. Sine movement is constructed from vector rotation with radius R and angular velocity ω.

For a 3-phase voltage source, each phase has a 120° difference is shown in figure 4.c. The original sine wave graph is shown on the dashed line, the rectified sine wave is indicated as a thin line while the result rectified sine wave is shown as a thick line.

The equation for the three-phase sine wave is shown in equations (5)-(7)

$$V_R(t) = A\,sin(\omega t) \quad (5)$$

$$V_S(t) = A\,sin(\omega t + 120°) \quad (6)$$

$$V_T(t) = A\,sin(\omega t - 120°) \quad (7)$$

The equation of three phases rectified sine wave is shown in equation (8)

$$Vout(t) = \begin{cases} V_R, & if((V_R(t) > V_S(t)) \cap \left((V_R(t) > V_T(t)\right)\right) \\ V_S & if((V_S(t) > V_R(t)) \cap \left((V_S(t) > V_T(t)\right)\right) \\ V_T & if((V_T(t) > V_S(t)] \cap \left((V_T(t) > V_R(t)\right)\right) \end{cases} \tag{8}$$

Construction protocol for an animated single sine wave is shown in Fig.5

	Name	Description	Value
1	Angle θ		θ = 19°
2	Function f	If(2 < t < 2 + 2π, sin(t + θ))	f(t) = If(2 < t < 2 + 2π, sin(t + 19°))
3	Vector u	Vector((0, 0), (1; 2 + θ))	u = (-0.69, 0.72)
4	Circle c	Circle with center (0, 0) and radius 1	c: x² + y² = 1

FIGURE 7. *Construction Protocol for animated sine wave*

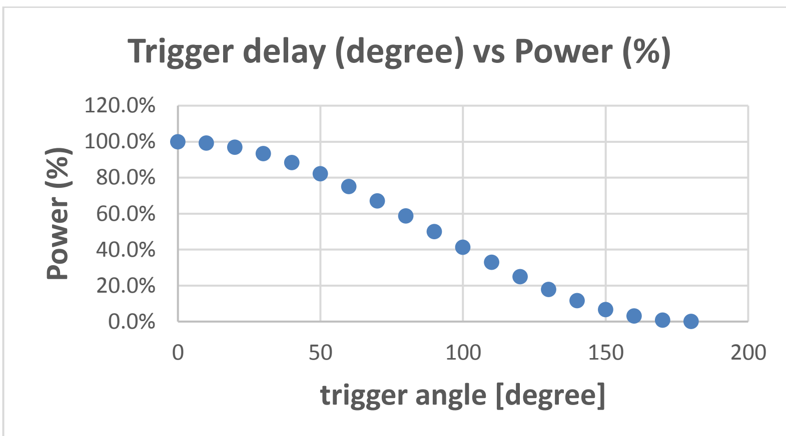


FIGURE 8. *Trigger delay vs Power*

Fig.4d is a sine wave with a delayed trigger. Visualization is performed by calculating integral operations of a sine wave with a lower limit value of θ (in angular units) of the delayed trigger used in the SCR (Silicon Controlled Rectifier) component as shown in Fig.6. The delay starts when zero-crossing reaches a certain angle of θ. After triggering occurs then SCR becomes ON and sine waves can flow.

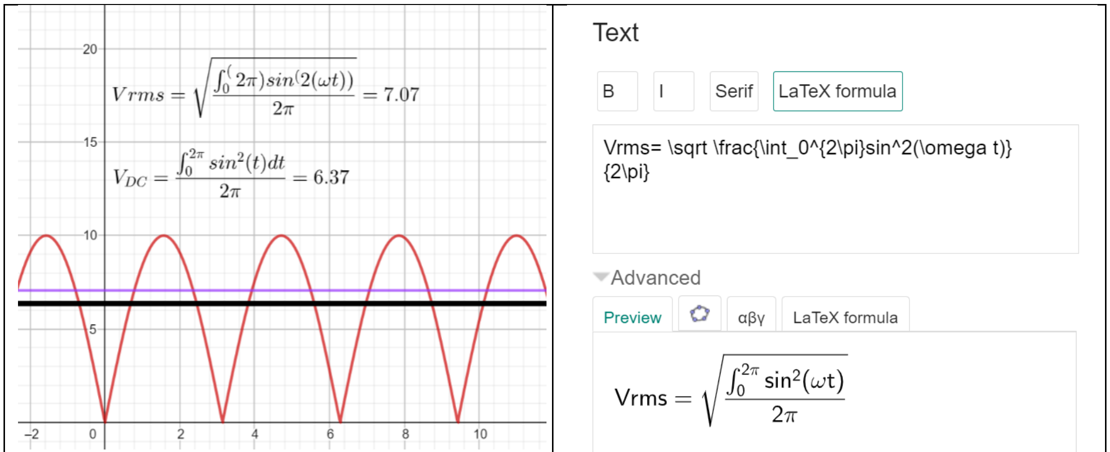
Calculation of half-wave rectifier voltage, full-wave rectifier, and RMS voltage are shown in Eq.(9)–(11)

$$V_{rms}(t) = \sqrt{\frac{\int_0^{2\pi} \sin^2(\omega t)\, dt}{2\pi}} \tag{9}$$

$$V_{half}(t) = \frac{\int_0^{\pi} \sin(\omega t)}{2\pi} \tag{10}$$

$$V_{full}(t) = \frac{\int_0^{\pi} \sin(\omega t)}{\pi} \tag{11}$$

The display on the graphics with a formula latex format is shown in figure 7.



(a)) Graph and formula with value

(b) formula writing using latex

FIGURE 9. *Display graphics with formula text and latex construction*

The rotating field visualization uses variables phasor amplitude with fixed phasors angle at a three-phase voltage source. This visualization is used on three-phase induction motors. 3 phasers are representing three voltage sources. Each phase is a difference of 120 degrees. Phasor magnitude is a function of sine amplitude. From the phasor movement, the rotation that occurs is CW or CCW depending on the phasor sequence.

CONCLUSION

From the results of the experiments that have been conducted, it can be concluded as follows

1. Visualization of voltages before rectified or after rectified voltage for single-phase voltage and 3 phases are shown graphically using GeoGebra.
2. Visualizations in GeoGebra can be static graphics and dynamic graphics (animations). Animations in GeoGebra use sliding facilities that can be adjusted at speed.
3. Calculation of the average voltage values of halfwave and full-wave, trigger angle visualization for sine voltage was successfully performed using GeoGebra.
4. To display the text formula on the chart is done using latex format, then students need to learn the use of latex to write mathematical equations

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