Basic Electrical and Electronics Engineering

LECTURE 2.3

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BEEE102L

Basic Electrical and Electronics Engineering

1. DC Circuits
2. **AC Circuits**
3. Magnetic Circuits
4. Electrical Machines
5. Semiconductor Devices and Applications
6. Digital Systems
7. Sensors and Transducers

Books

Text Book

[1] John Bird, 'Electrical circuit theory and technology', Newnes publications, 4th Edition, 2010.

Reference Book

[2] Allan R. Hambley, 'Electrical Engineering - Principles & Applications' Pearson Education, First Impression, 6/e, 2013.

[3] Simon Haykin, 'Communication Systems' , John Wiley & Sons, 5th Edition, 2009.

[4] Charles K Alexander , Mathew N O Sadiku, 'Fundamentals of Electric Circuits', Tata Mc Graw Hill , 2012.

[5] Batarseh, 'Power Electronics Circuits', Wiley, 2003.

[6] W. H. Hayt, J. E. Kemmerly and S. M. Durbin, 'Engineering Circuit Analysis', 6/e, Tata McGraw Hill, New Delhi, 2011.

[7] Fitzger ald, Higgabogan, Grabel, 'Basic Electrical Engineering', 5th ed, McGraw Hill, 2009.

[8] S.L.Uppal, 'Electrical Wiring Estimating and Costing' , Khannapublishers, NewDelhi, 2008.

Module II. AC Circuits

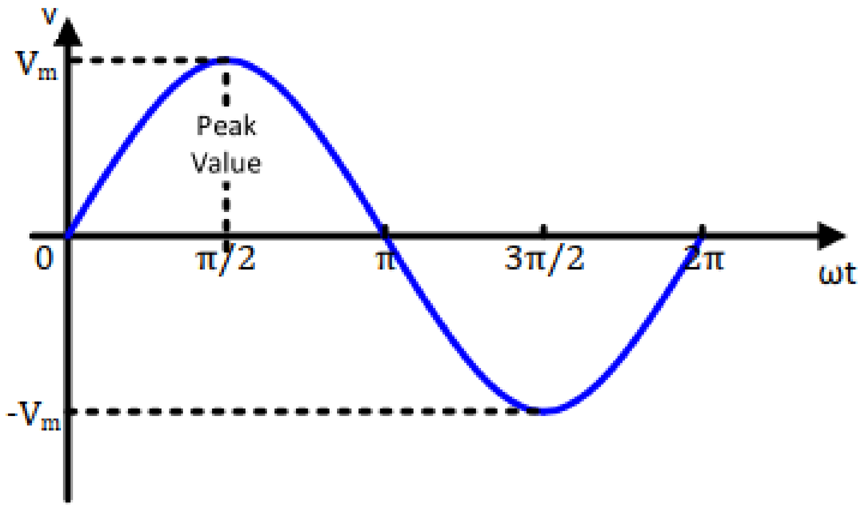
Alternating voltages and currents, AC values,
Single Phase RL, RC, RLC Series circuits,
Power in AC circuits - Power Factor,
Three Phase Systems,
Star and Delta Connection,
Three Phase Power Measurement,
Electrical Safety, Fuses and Earthing, Residential wiring.

Representation

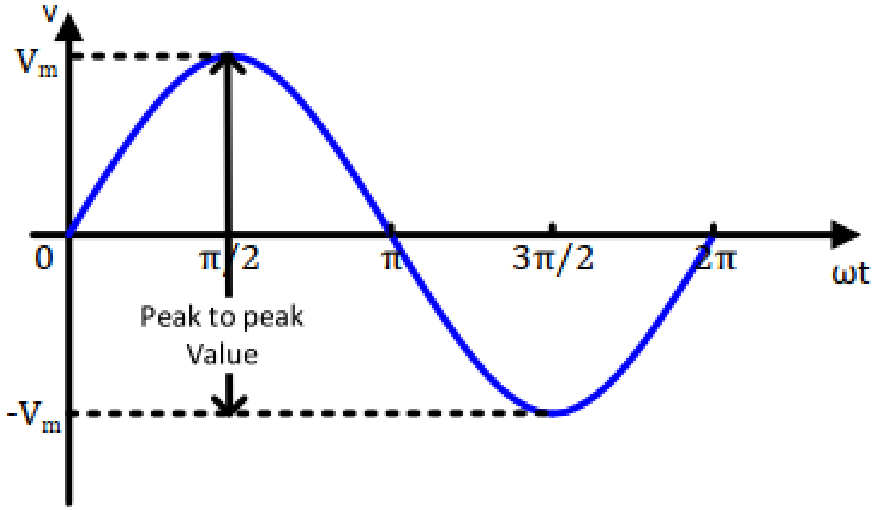
There are four ways to express the magnitude of an alternating voltage or current.

- Peak value
- Peak to peak value
- Average value
- RMS value

Peak value



Peak to peak value



Average Value

To find the average value of a waveform, divide the area under the waveform by the length of its base. Areas above the axis are counted as positive, while areas below the axis are counted as negative.

This approach is valid regardless of waveshape.

$$\text{average} = \frac{\text{area under curve}}{\text{length of base}}$$

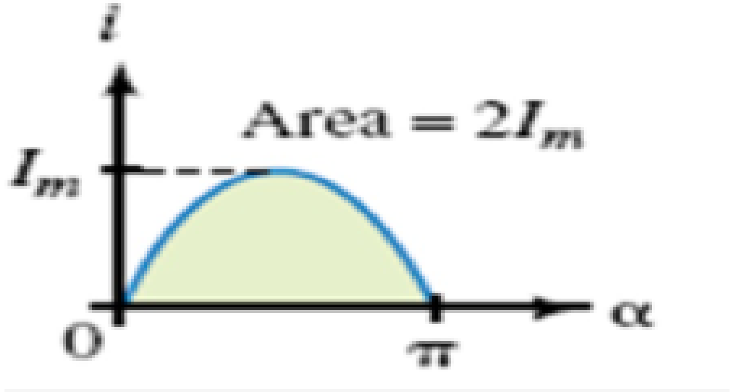
The averaging of all the instantaneous values along time axis with time being one full period, (T).

- The average value of alternating current (or voltage) over one cycle is zero. It is because the waveform is symmetrical about time axis and positive area exactly cancels the negative area. However, the average value over a half-cycle (positive or negative) is not zero. *Therefore, average value of alternating current (or voltage) means half-cycle average value unless stated otherwise*.

- The half-cycle average value of a.c. is that value of steady current (d.c.) which would send the same amount of charge through a circuit for half the time period of a.c. as is sent by the a.c. through the same circuit in the same time.

Sine Wave Averages

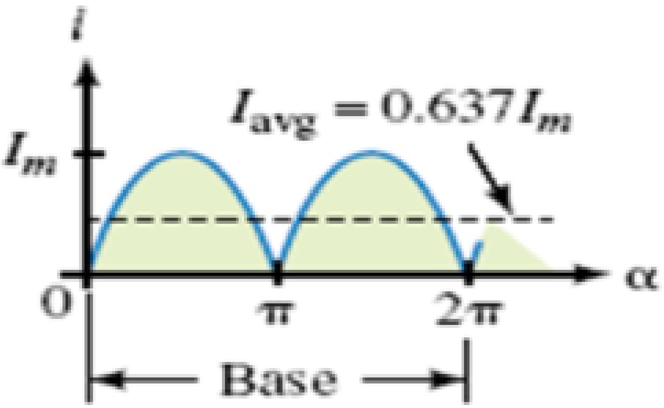
$$\text{area} = \int_0^\pi I_m \sin\alpha \, d\alpha = -I_m \cos\alpha \Big[_0^\pi = 2I_m$$

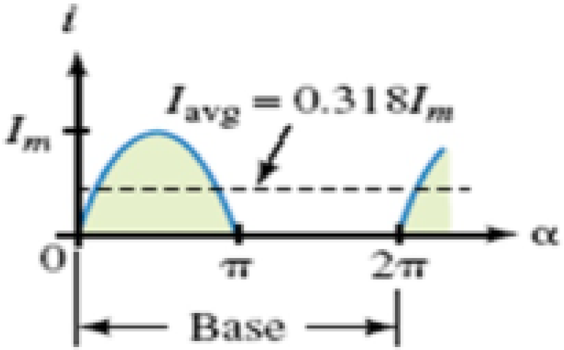


$$\text{Average Value } I_{av} = \frac{\text{Area of half-cycle}}{\text{Base length of half-cycle}} = \frac{2I_m}{\pi}$$

$$I_{av} = 0.637 I_m$$

full-wave average and half-wave average





$$I_{avg} = \frac{2(2I_m)}{2\pi} = \frac{2I_m}{\pi} = 0.637I_m$$

$$I_{avg} = \frac{2I_m}{2\pi} = \frac{I_m}{\pi} = 0.318I_m$$

$$V_{avg} = 0.637V_m \quad \text{(full-wave)}$$

$$V_{avg} = 0.318V_m \quad \text{(half-wave)}$$

Root mean square (RMS) value/ Effective Values

- **The effective or RMS value of an alternating current is that steady current (DC) which when flowing through a given resistance for a given time produces the same amount of heat as produced by the alternating current when flowing through the same resistance for the same time**

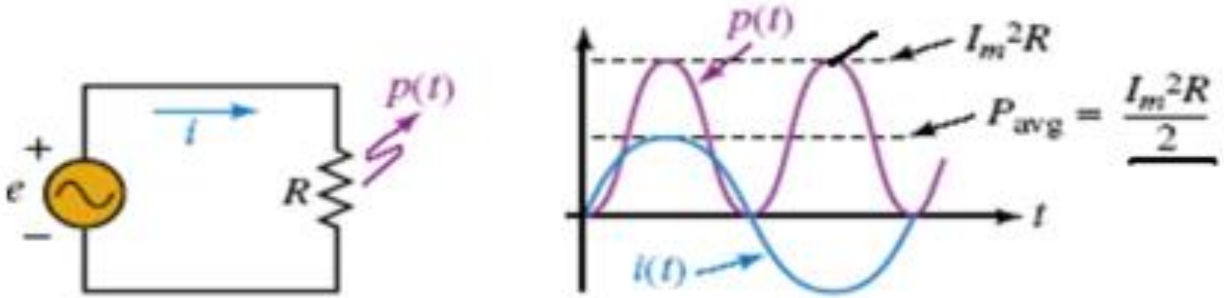
An effective value is an equivalent dc value:

it tells you how many volts or amps of dc that a time-varying waveform is equal to in terms of its ability to produce average power.

Effective values depend on the waveform.

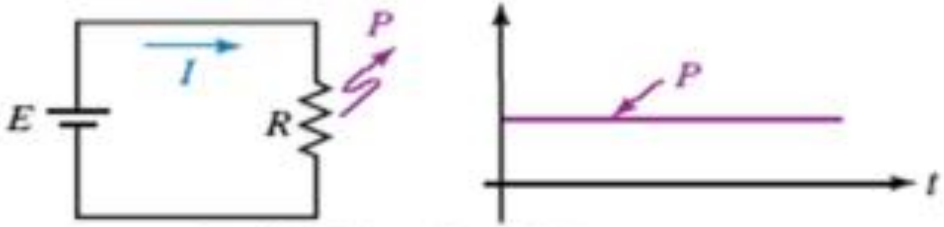
Effective Values for Sine Waves

$$\boldsymbol{i(t) = I_m \sin(\omega t)}$$



$p(t) = i^2R$. Therefore, $p(t)$ varies cyclically.

(a) AC circuit



$P = I^2R$. Therefore, P is constant.

(b) DC circuit

$$p(t) = i^2R = (I_m \sin \omega t)^2 R = I_m{}^2 R \sin^2 \omega t = I_m{}^2 R\left[\frac{1}{2}(1 - \cos 2\omega t)\right]$$

$$p(t) = \frac{I_m{}^2R}{2} - \frac{I_m{}^2R}{2}\cos 2\omega t$$

$$P_{avg} = \text{average of } p(t) = \frac{I_m{}^2R}{2}$$

$$P_{avg} = P = I^2R$$

SELECT

the average of cos $2\omega t$ is zero

$P_{avg} = \text{average of } p(t) = \frac{I_m^2 R}{2}$ = $P_{avg} = P = I^2 R$

$$\frac{I_m^2 R}{2} = I^2 R$$

$$I^2 = \frac{I_m^2}{2}$$

$$I = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

$$I_{eff} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

Problem

An alternating voltage has the equation $v = 141.4 \sin 377t$, what are the values of:

(a) r.m.s. voltage;
(b) frequency;
(c) the instantaneous voltage when $t = 3$ ms?

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The relation is of the form $v = V_m \sin \omega t$ and, by comparison,

(a) $V_m = 141.4\ \text{V} = \sqrt{2}V$

hence $V = \dfrac{141.4}{\sqrt{2}} = 100\ \text{V}$

(b) Also by comparison

$\omega = 377\ \text{rad/s} = 2\pi f$

hence $f = \dfrac{377}{2\pi} = 60\ \text{Hz}$

(c) Finally

$v = 141.4 \sin 377t$

When $t = 3 \times 10^{-3}$ s

$v = 141.4 \sin(377 \times 3 \times 10^{-3}) = 141.4 \sin 1.131$

$= 141.4 \times 0.904 = 127.8\ \text{V}$

Note that, in this example, it was necessary to determine the sine of 1.131 rad, which could be obtained either from suitable tables, or from a calculator. Alternatively, 1.131 rad may be converted into degree measurement, i.e.

$$1.131\ \text{rad} \equiv 1.131 \times \frac{180}{\pi} = 64.8°$$

EXAMPLE Determine the effective values of

a. $i = 10 \sin \omega t$ A,

b. $i = 50 \sin(\omega t + 20°)$ mA,

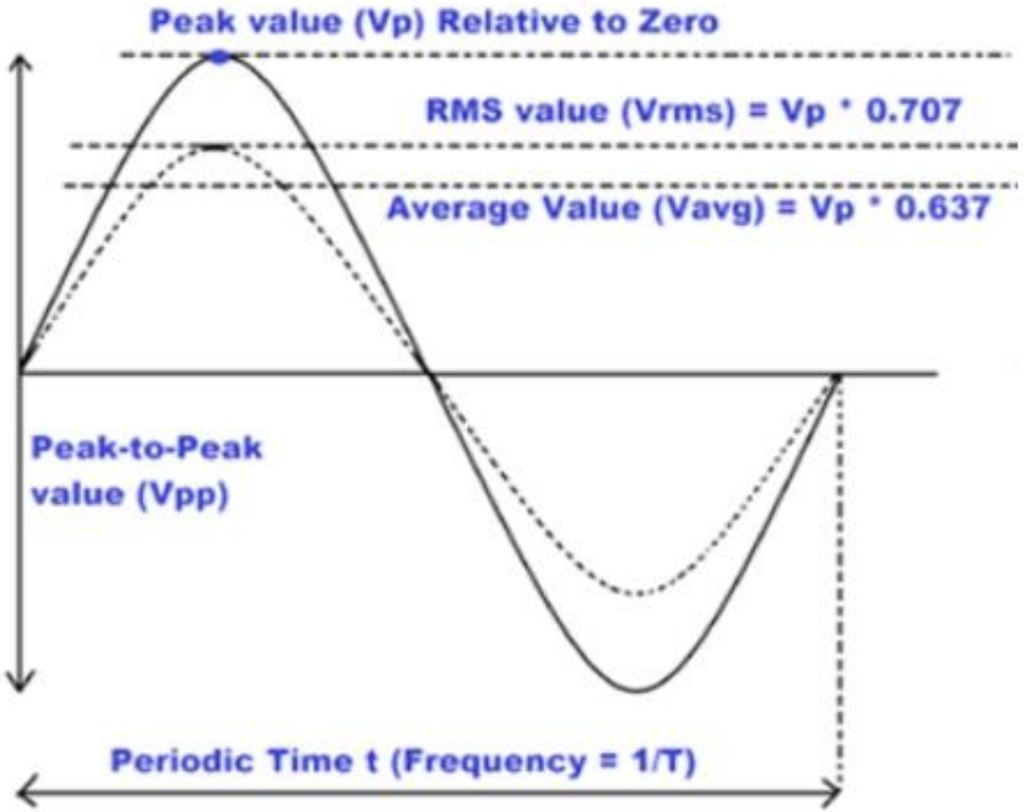
c. $v = 100 \cos 2\omega t$ V

Solution Since effective values depend only on magnitude,

a. $I_{eff} = (0.707)(10\text{ A}) = 7.07\text{ A}$,

b. $I_{eff} = (0.707)(50\text{ mA}) = 35.35\text{ mA}$,

c. $V_{eff} = (0.707)(100\text{ V}) = 70.7\text{ V}$.



$$V_{P-P} = 2V_m$$

$$V_{av} = 0.637V_m$$

$$V_{rms} = 0.707V_m$$

$$V_m = 1.414V_{rms}$$

Note:

✓ The domestic a.c. supply is 230 V, 50 Hz. It is the r.m.s. or effective value.

$$v = V_m sin(\omega t)$$

$$v = 230 \times \sqrt{2}\, sin(2\pi f \times t)$$

$$v = 230 \times \sqrt{2}\, sin(314t)$$

Form factor

The ratio of r.m.s. value to the average value of an alternating quantity is known as form factor.

$$\text{Form factor} = \frac{\text{R.M.S value}}{\text{Average value}}$$

$$\text{Form factor} = \frac{0.707 \times \text{Max.value}}{0.637 \times \text{Max.value}} = 1.11$$

Peak factor

The ratio of maximum value to the r.m.s. value of an alternating quantity is known as peak factor.

$$\text{Peak factor} = \frac{\text{Max. value}}{\text{R.M.S. value}}$$

$$\text{Peak factor} = \frac{\text{Max.value}}{0.707 \times \text{Max.value}} = 1.414$$

Example

Find the amplitude, phase, period, and frequency of the sinusoid

$$v(t) = 12sin(50t + 10^o)$$

Solution:

The amplitude is $v_m = 12\ V$

The phase is $\emptyset = 10°$

The angular frequency is $\omega = 50\ rad/s$

The period $T = \frac{2\pi}{\omega} = \frac{2\pi}{50} = 0.1257s$

The frequency is $f = \frac{1}{T} = 7.958Hz$

Problem

Problem The current in an a.c. circuit at any time t seconds is given by: $i = 120 \sin(100\pi t + 0.36)$ amperes. Find:

(a) the peak value, the periodic time, the frequency and phase angle relative to $120 \sin 100\pi t$

(b) the value of the current when $t = 0$

(c) the value of the current when $t = 8$ ms

(d) the time when the current first reaches 60 A, and

(e) the time when the current is first a maximum

Solution

$$i = 120\sin(100\pi t + 0.36) \text{ amperes.}$$

(a) Peak value = **120 A**

$$\text{Periodic time } T = \frac{2\pi}{\omega} = \frac{2\pi}{100\pi} \text{ (since } \omega = 100\pi)$$

$$= \frac{1}{50} = \mathbf{0.02\ s\ or\ 20\ ms}$$

$$\text{Frequency, } f = \frac{1}{T} = \frac{1}{0.02} = \mathbf{50\ Hz}$$

$$\text{Phase angle} = 0.36 \text{ rads} = \left(0.36 \times \frac{180}{\pi}\right)^{\circ} = \mathbf{20^{\circ}38' \ leading}$$

Solution

$$i = 120\sin(100\pi t + 0.36) \text{ amperes.}$$

(b) When $t = 0$, $i = 120\sin(0 + 0.36) = 120\sin 20°38' = \mathbf{49.3\ A}$

(c) When $t = 8$ ms, $i = 120\sin\left[100\pi\left(\frac{8}{10^3}\right) + 0.36\right]$

$$= 120\sin 2.8733 (= 120\sin 164°38') = \mathbf{31.8\ A}$$

(d) When $i = 60$ A, $60 = 120\sin(100\pi t + 0.36)$

thus $\frac{60}{120} = \sin(100\pi t + 0.36)$

so that $(100\pi t + 0.36) = \arcsin 0.5 = 30° = \frac{\pi}{6}$ rads $= 0.5236$ rads

Hence time, $t = \frac{0.5236 - 0.36}{100\pi} = \mathbf{0.521\ ms}$

Solution

$$i = 120\sin(100\pi t + 0.36) \text{ amperes.}$$

(e) When the current is a maximum, $i = 120$ A

Thus $120 = 120\sin(100\pi t + 0.36)$

$$1 = \sin(100\pi t + 0.36)$$

$$(100\pi t + 0.36) = \arcsin 1 = 90^\circ = \frac{\pi}{2} \text{ rads} = 1.5708 \text{ rads}$$

Hence time, $t = \dfrac{1.5708 - 0.36}{100\pi} = \mathbf{3.85\ ms}$