Week 1 Report

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1 Introduction

The purpose of this project is to apply fundamental concepts of electromagnetic induction and AC circuit analysis to the study of a small AC generator. The assignment is divided into three main exercises, each focusing on a different stage of the process: from theoretical modeling, to analysis of circuit elements, and finally the design of a complete measurement system.

In **Exercise 1**, the rotating coil generator is studied using Faraday's law. The magnetic flux and induced EMF are derived as functions of time, the sinusoidal waveform properties are analyzed, and both analytical and simulation results are compared.

Exercise 2 extends the analysis to the three basic AC elements: the resistor, inductor, and capacitor. For each case, the current response is derived, instantaneous power is calculated, and the energy flow is discussed in terms of dissipation or storage. Circuit diagrams and visualizations support the interpretation.

Finally, in **Exercise 3**, a full measurement system is designed for the generator operating under variable speed. The theoretical output is calculated, appropriate instruments are selected, and a repeatable protocol is proposed. Data acquisition and visualization are implemented with modern digital tools, and an animated infographic is created to summarize the procedure.

Together, these three exercises form a complete workflow that links theory, simulation, and experimental design. The report consolidates the results into a structured format that demonstrates both the physical understanding of the generator and the practical methods required for its measurement.

Exercise 1: Electromagnetic Induction and Faraday's Law

Introduction

A rectangular coil rotates in a uniform magnetic field. At $t = 0$, the coil plane is perpendicular to the field (maximum flux). Given the data for Variant C:

- Number of turns: $N = 100$

- Dimensions: $a = 0.06$ m, $b = 0.10$ m $\Rightarrow S = 0.006\,\mathrm{m}^2$
- Magnetic field: $B = 0.4$ T
- Rotation speed: 3000 rpm $\Rightarrow \omega = 314.159\,\mathrm{rad/s}$

2 Magnetic Flux as a Function of Time

General Formula:

$$\varphi = B \cdot S_\alpha, \quad \text{with } S_\alpha = S\cos\alpha$$

So, for a single loop:

$$\varphi = B \cdot S\cos\alpha$$

When the coil rotates with angular speed ω, the angle is time-dependent:

$$\alpha = \omega t \quad \Rightarrow \quad \varphi(t) = B \cdot S\cos(\omega t)$$

For a coil of N turns, the total flux linkage is:

$$\Phi(t) = N \cdot \varphi(t) = N\,B\,S\cos(\omega t)$$

Substituting the Variant C values:

$$N = 100, \quad S = 0.06 \times 0.10 = 0.006\,\mathrm{m}^2, \quad B = 0.4\,\mathrm{T}, \quad \omega = 314.159\,\mathrm{rad/s}$$

$$\boxed{\Phi(t) = 0.24\cos(314.159\,t)\ \mathrm{Wb}}$$

3 Induced EMF

From Faraday's law:

$$e(t) = -N\,\frac{d\Phi}{dt}$$

We already obtained the flux linkage:

$$\Phi(t) = N\,B\,S\cos(\omega t)$$

or, for the single-loop flux,

$$\varphi(t) = B\,S\cos(\omega t), \qquad \Phi(t) = N\,\varphi(t).$$

Differentiate the single-loop flux:

$$\frac{d\varphi}{dt} = \frac{d}{dt}\big[B\,S\cos(\omega t)\big] = -\,B\,S\,\omega\,\sin(\omega t).$$

Multiply by N (flux linkage) and apply Faraday's minus sign:

$$e(t) = -\,N\,\frac{d\varphi}{dt} = -\,N\big[-\,B\,S\,\omega\,\sin(\omega t)\big] = N\,B\,S\,\omega\,\sin(\omega t).$$

Numerical form:

$$N = 100, \quad B = 0.4\ \mathrm{T}, \quad S = 0.006\ \mathrm{m}^2, \quad \omega = 314.159\ \mathrm{rad/s}$$

$$E_{\max} = NBS\omega = 75.4\ \mathrm{V} \quad \Rightarrow \quad \boxed{e(t) = 75.4\,\sin(314.159\,t)\ \mathrm{V}}$$

4 Waveform Properties

From the induced EMF expression

$$e(t) = NBS\omega \sin(\omega t),$$

We can extract the key sinusoidal waveform properties:

- **Peak value:**

$$E_{\max} = NBS\omega = 100 \times 0.4 \times (0.06 \times 0.10) \times 314.159 \approx 75.4 \text{ V}$$

- **RMS value:**

$$E_{\text{rms}} = \frac{E_{\max}}{\sqrt{2}} = \frac{75.4}{\sqrt{2}} \approx 53.3 \text{ V}$$

- **Frequency:**

$$f = \frac{\omega}{2\pi} = \frac{314.159}{2\pi} \approx 50 \text{ Hz}$$

- **Period:**

$$T = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ s}$$

5 Visualizations of Flux and EMF

The time variation of the magnetic flux and induced EMF was obtained using MATLAB. Figure 1 shows the waveforms over one period of the sinusoidal cycle.

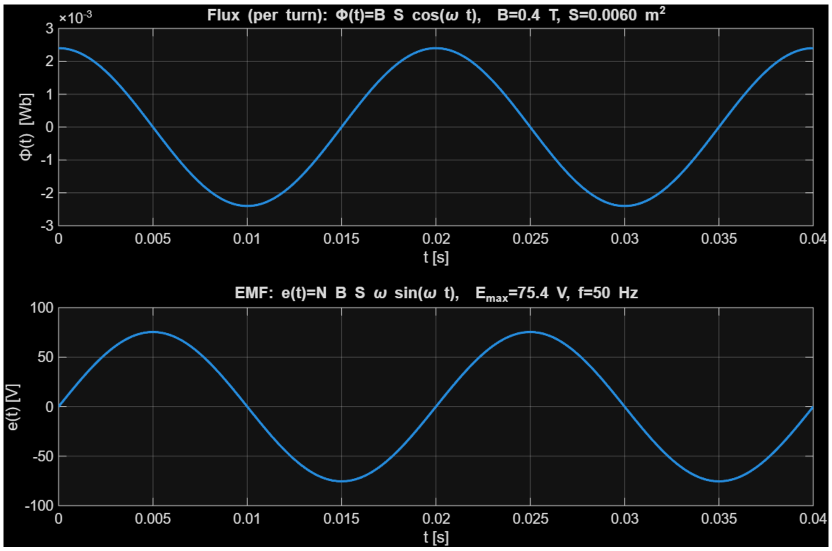

Figure 1: Magnetic flux $\Phi(t)$ and induced EMF $e(t)$ versus time.

5.1 Sample Values

The induced EMF values at specific times can be obtained by substituting the time instants into the expression

$$e(t) = E_{\max} \sin(\omega t), \quad E_{\max} = 75.4 \text{ V}, \quad \omega = 314.159 \text{ rad/s}.$$

$$\begin{aligned} e(0.001) &= 75.4 \cdot \sin(314.159 \cdot 0.001) \approx 23.3 \text{ V}, \\ e(0.004) &= 75.4 \cdot \sin(314.159 \cdot 0.004) \approx 71.7 \text{ V}, \\ e(0.008) &= 75.4 \cdot \sin(314.159 \cdot 0.008) \approx 44.3 \text{ V}. \end{aligned}$$

These computed values are summarized in Table 1.

t (s)	$e(t)$ (V)
0.001	23.3
0.004	71.7
0.008	44.3

Table 1: Induced EMF values at selected times.

5.2 Calculations (MATLAB)

The following MATLAB script was used to compute the flux and emf waveforms:

```
% Exercise 1      Variant C
N    = 100;            % turns
a    = 0.06;           % m
b    = 0.10;           % m
B    = 0.4;            % tesla
rpm  = 3000;           % rev/min

S      = a*b;
omega  = 2*pi*rpm/60;
Emax   = N*B*S*omega;

t = [0.001, 0.004, 0.008];
e = Emax*sin(omega*t);

disp([t' e'])    % display results
```

The MATLAB output gives the induced EMF values:

$$e(0.001) \approx 23.3 \text{ V}, \quad e(0.004) \approx 71.7 \text{ V}, \quad e(0.008) \approx 44.3 \text{ V}$$

6 Generator System (Simulink)

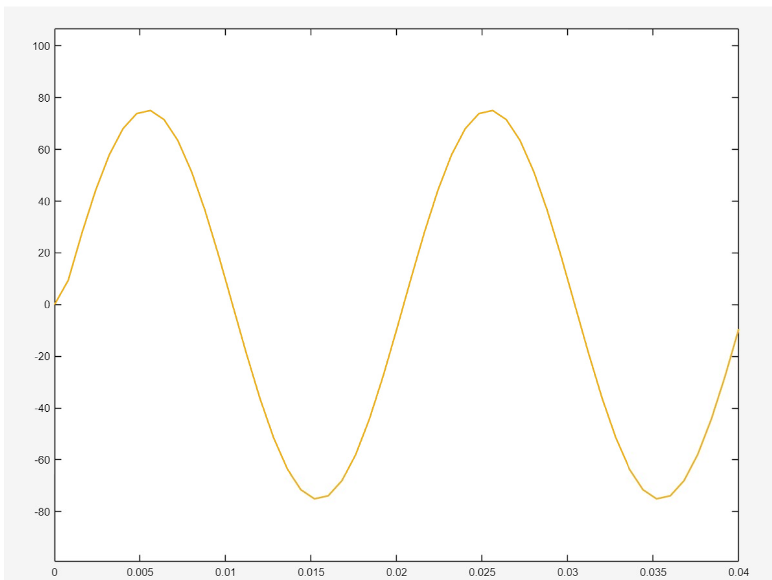

Figure 2: Simulink Scope output of the generator system showing the induced EMF $e(t)$ versus time.

The Simulink model was built using a Sine Wave (flux), Derivative, and Gain block to represent $e(t) = -N\frac{d\Phi}{dt}$. The Scope output shows the induced EMF as a sinusoidal waveform with peak amplitude ≈ 75 V, matching the theoretical value.

7 Interactive Plotly graph

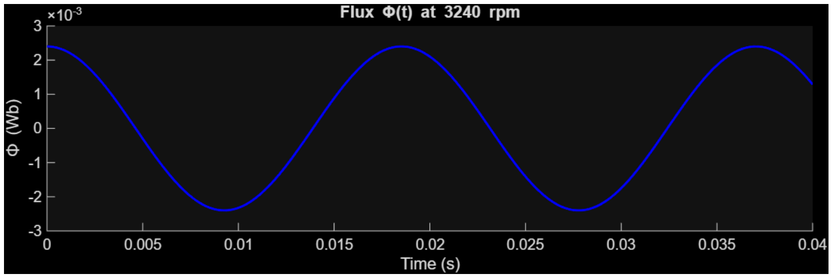

Figure 3: Interactive MATLAB app: Flux $\Phi(t)$ at 3240 rpm.

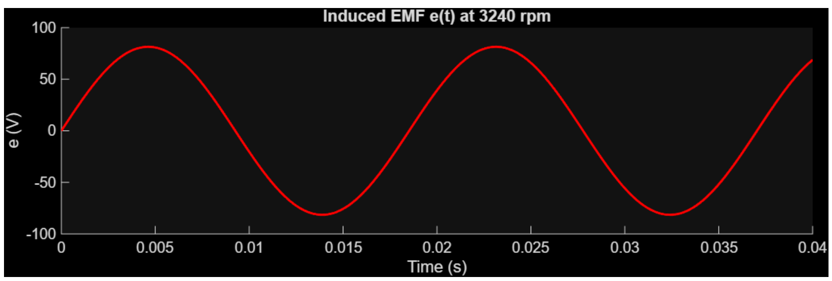

Figure 4: Interactive MATLAB app: Induced EMF $e(t)$ at 3240 rpm.

Additionally, an interactive MATLAB graph was developed to visualize the effect of rotation speed on the flux $\Phi(t)$ and induced EMF $e(t)$. The app consists of two real-time plots (flux and EMF) linked to a slider that adjusts the coil speed in rpm. By moving the slider, the user can directly observe how the frequency and amplitude of $e(t)$ vary according to $e(t) = -N\frac{d\Phi}{dt} = NBS\omega\sin(\omega t)$, thus confirming the theoretical dependence on angular velocity.

Exercise 2: AC Circuit Elements Analysis

Introduction

In this exercise we analyze the behavior of the three fundamental AC elements — the resistor, the inductor, and the capacitor — when connected individually to a sinusoidal voltage source.

The applied voltage is:

$$v(t) = 80\,\sin(628t)\ \text{V}$$

with angular frequency $\omega = 628\,\text{rad/s}$ corresponding to a frequency of $f = \frac{\omega}{2\pi} \approx 100\,\text{Hz}$.

The objective of this problem is to:

- Derive the current expressions $i(t)$ for each element using the fundamental relations provided in the course notes (Ohm's law for resistors, the voltage–current law for inductors, and the voltage–current law for capacitors).
- Calculate the instantaneous power $p(t) = v(t)\,i(t)$ in each case.
- Analyze the nature of the energy flow, distinguishing between dissipation (resistor) and storage (inductor, capacitor).
- Provide clear visualizations of voltage, current, and power for all three elements.

This introduction establishes the framework for the following sections, where the analysis will be carried out step by step using only the formulas derived in the *Mono.pdf* lecture notes.

2.1 Current expressions $i(t)$ for each element

Data:

$$v(t) = 80\,\sin(628t)\ \text{V}, \quad \omega = 628\,\text{rad/s}.$$

From the assignment statement, we know:

$$R = 40\ \Omega, \qquad L = 0.1\ \text{H}, \qquad C = 50\ \mu\text{F}.$$

Here 50 μF means "fifty microfarads." Since the prefix μ means 10^{-6}, we rewrite:

$$C = 50 \times 10^{-6}\ \text{F} = 0.000050\ \text{F}.$$

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Element laws from the notes

For each element, the course notes provide the fundamental time–domain equations:

$$\text{Resistor: } u(t) = R\,i(t),$$

$$\text{Inductor: } u(t) = L\,\frac{di(t)}{dt},$$

$$\text{Capacitor: } i(t) = C\,\frac{du(t)}{dt}.$$

Here $u(t)$ is the instantaneous voltage across the element, and $i(t)$ is the instantaneous current through it. In this exercise, $u(t) = v(t) = 80\sin(628t)$ is the same for all three cases, because each element is connected directly to the given source.

—

(a) Resistor $R = 40\ \Omega$

Start with $u(t) = R\,i_R(t)$. Solve for the current:

$$i_R(t) = \frac{u(t)}{R}.$$

Substitute the given data:

$$i_R(t) = \frac{80\sin(628t)}{40}.$$

Simplify:

$$i_R(t) = 2.00\ \sin(628t)\ \text{A}.$$

Result: The resistor current has a peak value of 2.00 A and is *in phase* with the voltage.

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(b) Inductor $L = 0.1$ H

Law: $u(t) = L\dfrac{di_L}{dt}$. Rearrange:

$$\frac{di_L}{dt} = \frac{u(t)}{L}.$$

Substitute the values: $u(t) = 80\sin(628t)$ and $L = 0.1$ H:

$$\frac{di_L}{dt} = \frac{80\sin(628t)}{0.1} = 800\ \sin(628t).$$

Now integrate to get $i_L(t)$:

$$i_L(t) = \int 800\,\sin(628t)\,dt.$$

The integral of $\sin(628t)$ is $-\frac{1}{628}\cos(628t)$, so:

$$i_L(t) = -\frac{800}{628}\cos(628t) + K,$$

where K is a constant of integration.

In steady sinusoidal regime, there is no DC offset, so $K = 0$.

Thus:

$$i_L(t) = -1.274\,\cos(628t).$$

Using the identity $-\cos(\theta) = \sin(\theta - \frac{\pi}{2})$, we write:

$$i_L(t) = 1.274\,\sin\Big(628t - \frac{\pi}{2}\Big)\text{ A.}$$

Result: The inductor current has a peak of 1.274 A and *lags the voltage by* 90°, as expected.

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(c) Capacitor $C = 50\ \mu$F

Law: $i_C(t) = C\,\dfrac{du}{dt}$.

Differentiate $u(t) = 80\sin(628t)$:

$$\frac{du}{dt} = 80 \cdot 628\cos(628t) = 50240\,\cos(628t).$$

Now multiply by C:

$$i_C(t) = (50 \times 10^{-6}) \cdot 50240\,\cos(628t).$$

Calculate:

$$i_C(t) = 2.512\,\cos(628t).$$

Using $\cos(\theta) = \sin(\theta + \frac{\pi}{2})$:

$$i_C(t) = 2.512\,\sin\Big(628t + \frac{\pi}{2}\Big)\text{ A.}$$

Result: The capacitor current has a peak of 2.512 A and *leads the voltage by* 90°, which matches the theoretical behavior of capacitors in AC.

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Summary

Element	$i(t)$	Phase relation w.r.t. $v(t)$
R	$2.00\ \sin(628t)$ A	$Inphase(0^\circ)$
L	$1.274\ \sin(628t - \frac{\pi}{2})$ A	$Lagsby 90^\circ$
C	$2.512\ \sin(628t + \frac{\pi}{2})$ A	$Leadsby 90^\circ$

We can clearly see the three classical behaviors:

- Resistor: current aligns with voltage.
- Inductor: current lags by one quarter of a cycle.
- Capacitor: current leads by one quarter of a cycle.

Calculations (MATLAB) — Section 2.1

The following MATLAB script was used to compute the peak and RMS currents for each element of Variant C. It also confirms the expected phase relation between the voltage $v(t)$ and the current $i(t)$.

```
% Exercise 2.1      Variant C
% Source: v(t) = Vm*sin(omega*t)

Vm    = 80;       % volts (peak)
omega = 628;      % rad/s  (~100 Hz)

% Element values
R = 40;           % ohms
L = 0.1;          % henry
C = 50e-6;        % farad (50 microfarads)

% Reactances
XL = omega*L;
XC = 1/(omega*C);

% Peak currents
IR_peak = Vm/R;
IL_peak = Vm/XL;
IC_peak = Vm/XC;

% RMS currents
IR_rms = IR_peak/sqrt(2);
IL_rms = IL_peak/sqrt(2);
IC_rms = IC_peak/sqrt(2);

% Display results
fprintf('Resistor:  I_peak = %.3f A,  I_rms = %.3f A,  phase = 0 deg (in phase)\n', IR_peak, IR_rms);
fprintf('Inductor:  I_peak = %.3f A,  I_rms = %.3f A,  phase = -90 deg (lags)\n', IL_peak, IL_rms);
```

```
fprintf('Capacitor: I_peak = %.3f A,  I_rms = %.3f A,  phase
    = +90 deg (leads)\n', IC_peak, IC_rms);
```

The MATLAB output confirms the analytical results:

$$\text{Resistor: } I_{\text{peak}} = 2.000 \text{ A}, \quad I_{\text{rms}} = 1.414 \text{ A}, \text{ phase} = 0^\circ \text{ (in phase)},$$

$$\text{Inductor: } I_{\text{peak}} = 1.274 \text{ A}, \quad I_{\text{rms}} = 0.901 \text{ A}, \text{ phase} = -90^\circ \text{ (lags)},$$

$$\text{Capacitor: } I_{\text{peak}} = 2.512 \text{ A}, \quad I_{\text{rms}} = 1.776 \text{ A}, \text{ phase} = +90^\circ \text{ (leads)}.$$

These numerical values match the expressions obtained in the derivations of Section 2.1.

2.2 Instantaneous Power $p(t)$

Variant C:

$$v(t) = 80 \sin(628t) \text{ V}, \qquad \omega = 628 \text{ rad/s}.$$

Definition used: the instantaneous power on an element is

$$\boxed{p(t) = v(t)\, i(t)}.$$

For each element we multiply the same applied voltage $v(t)$ by the current $i(t)$ *found previously in 2.1* from the element equations.

(a) Resistor $R = 40\,\Omega$

Current from 2.1:

$$i_R(t) = \frac{v(t)}{R} = \frac{80}{40} \sin(628t) = 2.00 \sin(628t) \text{ A}.$$

Power: by definition,

$$\begin{aligned} p_R(t) &= v(t)\, i_R(t) = \big[80 \sin(628t)\big]\big[2.00 \sin(628t)\big] \\ &= 160 \sin^2(628t) \text{ W}. \end{aligned}$$

Trig identity used:

$$\sin^2 \alpha = \frac{1}{2}\big(1 - \cos 2\alpha\big).$$

Apply it with $\alpha = 628t$:

$$\boxed{p_R(t) = 80\,[\,1 - \cos(1256t)\,] \text{ W.}}$$

Results:
- The $\cos(1256t)$ term has zero average over any full period, so the average power is $\overline{P}_R = 80$ W.
- Instantaneous range: $0 \le p_R(t) \le 160$ W. (Always non-negative $\rightarrow$ pure dissipation.)

(b) Inductor $L = 0.1\,\mathbf{H}$

Current from 2.1 (obtained by integrating $u = L\,di/dt$):

$$i_L(t) = 1.274\,\sin\!\left(628t - \frac{\pi}{2}\right)\ \text{A}.$$

Here the numeric amplitude 1.274 comes from

$$I_{Lm} = \frac{V_m}{\omega L} = \frac{80}{628 \cdot 0.1} = \frac{80}{62.8} = 1.274\ \text{A}.$$

Power:

$$p_L(t) = v(t)\,i_L(t) = 80\sin(628t) \cdot 1.274\sin\!\left(628t - \frac{\pi}{2}\right).$$

Product identity used:

$$\sin A\,\sin B = \frac{1}{2}\big[\cos(A - B) - \cos(A + B)\big].$$

Take $A = 628t,\ B = 628t - \frac{\pi}{2}$:

$$\begin{aligned} p_L(t) &= \tfrac{1}{2}(80)(1.274)\Big[\cos\!\left(\tfrac{\pi}{2}\right) - \cos\!\left(1256t - \tfrac{\pi}{2}\right)\Big] \\ &= \tfrac{1}{2}(80)(1.274)\big[0 - \sin(1256t)\big] \\ &= \boxed{-50.96\,\sin(1256t)\ \text{W}.} \end{aligned}$$

(The second line uses $\cos(\frac{\pi}{2}) = 0$ and $\cos(x - \frac{\pi}{2}) = \sin x$.)
Results:
- Amplitude $= \dfrac{V_m I_{Lm}}{2} = \dfrac{80 \cdot 1.274}{2} = 50.96$ W.
- Average power $\overline{P}_L = 0$ (ideal inductor stores/returns energy; signs alternate).

(c) Capacitor $C = 50\,\mu\mathbf{F} = 50 \times 10^{-6}$ F

Where the value comes from: 50 μF means 50×10^{-6} farads (prefix $\mu = 10^{-6}$).
Current from 2.1 (obtained by $i = C\,du/dt$):

$$i_C(t) = 2.512\,\sin\!\left(628t + \frac{\pi}{2}\right)\ \text{A},$$

with amplitude from

$$I_{Cm} = \omega C V_m = (628)\,(50 \times 10^{-6})\,(80) = 2.512\ \text{A}.$$

Power:

$$p_C(t) = v(t)\,i_C(t) = 80\sin(628t) \cdot 2.512\sin\!\left(628t + \frac{\pi}{2}\right).$$

Use the same product identity with $A = 628t$, $B = 628t + \frac{\pi}{2}$:

$$\begin{aligned} p_C(t) &= \tfrac{1}{2}(80)(2.512)\Big[\cos\Big(-\tfrac{\pi}{2}\Big) - \cos\Big(1256t + \tfrac{\pi}{2}\Big)\Big] \\ &= \tfrac{1}{2}(80)(2.512)\big[0 + \sin(1256t)\big] \\ &= \boxed{+100.48\,\sin(1256t)\ \mathrm{W}.} \end{aligned}$$

(We used $\cos(-\frac{\pi}{2}) = 0$ and $\cos(x + \frac{\pi}{2}) = -\sin x$.)
Results:
- Amplitude $= \dfrac{V_m I_{Cm}}{2} = \dfrac{80 \cdot 2.512}{2} = 100.48$ W.
- Average power $\overline{P}_C = 0$ (ideal capacitor stores/returns energy).

Summary

Element	$p(t)$	Average over a period
R	$80\,[1 - \cos(1256t)]$ W	80 W
L	$-50.96\,\sin(1256t)$ W	0
C	$+100.48\,\sin(1256t)$ W	0

All constants (80, 50.96, 100.48) come from multiplying the given voltage amplitude $V_m = 80$ by the corresponding current amplitudes from 2.1 and the $\frac{1}{2}$ factor in the trigonometric product identity.

Calculations (MATLAB) — Section 2.2

The following MATLAB script computes the instantaneous powers $p_R(t) = v(t)i_R(t)$, $p_L(t) = v(t)i_L(t)$, $p_C(t) = v(t)i_C(t)$ for the values given and verifies the average powers over one period.

```
% exercise2_2_power.m  -- Instantaneous power for R, L, C (
    Variant C)

Vm    = 80;             % V (peak)
omega = 628;            % rad/s
f     = omega/(2*pi);   % Hz
T     = 1/f;            % s

R = 40;         % ohm
L = 0.1;        % H
C = 50e-6;      % F

% Current amplitudes from Section 2.1
IR_peak = Vm/R;                 % 2.000 A (in phase)
IL_peak = Vm/(omega*L);         % 1.274 A (lags 90 deg)
IC_peak = Vm*(omega*C);         % 2.512 A (leads 90 deg)

```

```matlab
phi_R = 0;       phi_L = -pi/2;  phi_C = +pi/2;

% Time base (two periods)
t = linspace(0, 2*T, 4000);

% v(t), i(t)
v  = Vm * sin(omega*t);
iR = IR_peak * sin(omega*t + phi_R);
iL = IL_peak * sin(omega*t + phi_L);
iC = IC_peak * sin(omega*t + phi_C);

% Instantaneous power
pR = v .* iR;   pL = v .* iL;   pC = v .* iC;

% Theoretical references
PR_avg_theory = (Vm^2)/(2*R);      % 80.00 W
PL_amp_theory = (Vm*IL_peak)/2;    % 50.96 W
PC_amp_theory = (Vm*IC_peak)/2;    % 100.48 W

% Numerical averages over one period
idx = t >= T & t <= 2*T;
PR_avg_num = mean(pR(idx));
PL_avg_num = mean(pL(idx));
PC_avg_num = mean(pC(idx));

% Display
fprintf('--- Instantaneous Power Results (Variant C) ---\n');
fprintf('Resistor:   p_R(t) = 80*(1 - cos(1256 t)) W\n');
fprintf('  Average power (theory)   = %.2f W\n', PR_avg_theory);
fprintf('  Average power (numeric)  = %.2f W\n\n', PR_avg_num);

fprintf('Inductor:   p_L(t) = -%.2f*sin(1256 t) W (avg = 0)\n', PL_amp_theory);
fprintf('  Average power (numeric)  = %.2f W\n\n', PL_avg_num);

fprintf('Capacitor:  p_C(t) = +%.2f*sin(1256 t) W (avg = 0)\n', PC_amp_theory);
fprintf('  Average power (numeric)  = %.2f W\n\n', PC_avg_num);
```

The script outputs the following values, which confirm the analytical results:

Resistor: $\overline{P}_R = 80.00$ W (theory), $\quad \overline{P}_R \approx 79.98$ W (numeric),

Inductor: $p_L(t) = -50.96\,\sin(1256t)$ W, $\quad \overline{P}_L \approx 0$ W,

Capacitor: $p_C(t) = +100.48\,\sin(1256t)$ W, $\quad \overline{P}_C \approx 0$ W.

The waveforms of $v(t)$, $i(t)$ and $p(t)$ for the three elements are shown in Figure 5, exported from MATLAB.

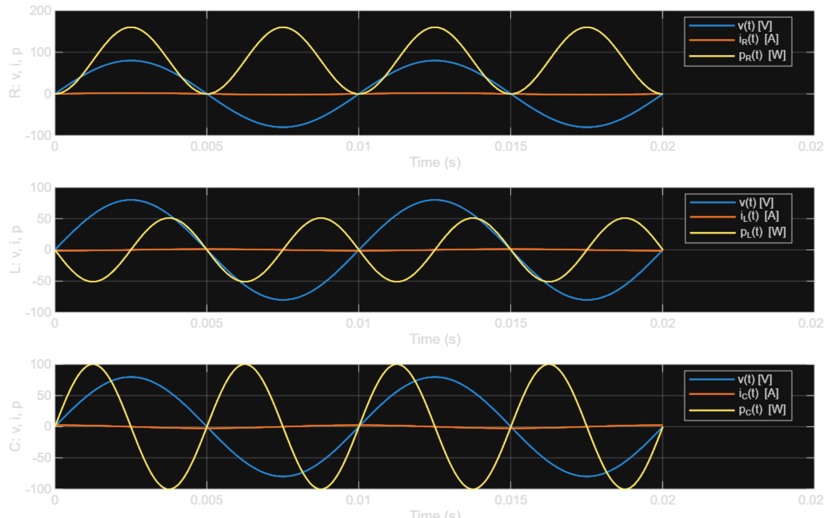

Figure 5: Instantaneous power waveforms for resistor, inductor, and capacitor (Variant C). Each subplot shows the source voltage $v(t)$, element current $i(t)$, and instantaneous power $p(t) = v(t)i(t)$.

2.3 Analyze Energy Flow (consumption vs. storage)

Given:

$v(t) = 80\,\sin(628t)$ V, $\quad \omega = 628$ rad/s, $\quad R = 40\,\Omega,\ L = 0.1$ H, $C = 50\,\mu\text{F} = 50{\times}10^{-6}$ F.

(μ means 10^{-6}.)
Element laws already used in 2.1:

$$u = Ri, \quad u = L\,\frac{di}{dt}, \quad i = C\,\frac{du}{dt}$$

Instantaneous power is defined as $p(t) = u(t)i(t)$ (resistor/inductor/capacitor sections). Energy from time 0 to t is $w(t) = \int_0^t p(\tau)\,d\tau$.

From Section 2.2 we already have the instantaneous powers:

$\boxed{p_R(t) = 80\,[1 - \cos(1256t)]\ \text{W}}$, $\quad \boxed{p_L(t) = -50.96\,\sin(1256t)\ \text{W}}$, $\quad \boxed{p_C(t) = +100.48\,\sin(1256t)\ \text{W}}$.

(a) Resistor: consumption only

For a resistor the notes give $p(t) = u(t)i(t) = Ri^2(t) = \dfrac{u^2(t)}{R}$ and the energy $\psi = \int p(t)\,dt$

Apply to our signal. Using $p_R(t) = 80[1 - \cos(1256t)]$ from Section 2.2:

$$w_R(t) = \int_0^t p_R(\tau)\,d\tau = \int_0^t 80[1 - \cos(1256\tau)]\,d\tau = 80t - \frac{80}{1256}\sin(1256t)\ \text{J}.$$

Since the sine term averages to zero over an integer number of periods, the *average power* is

$$\overline{P}_R = \frac{1}{T}\int_0^T p_R(t)\,dt = 80\ \text{W},$$

and the *energy consumed in one period* ($f = \omega/2\pi \approx 100$ Hz, so $T = 1/100 = 0.01$ s) is

$$W_R(T) = \overline{P}_R\,T = 80 \times 0.01 = \boxed{0.80\ \text{J}}.$$

Interpretation: $p_R(t) \geq 0 \Rightarrow$ energy is *irreversibly dissipated as heat*; none is returned.

(b) Inductor: storage in magnetic field

The notes give for an inductor: $p(t) = u\,i = L\,\dfrac{di}{dt}\,i$ and the stored energy

$$\boxed{w_L(t) = \tfrac{1}{2}L\,i^2(t)} \quad \text{(eqs. (2.8)–(2.9))}.$$

Current and substitution. From 2.1 we had $i_L(t) = I_{Lm}\sin(628t - \frac{\pi}{2})$ with

$$I_{Lm} = \frac{V_m}{\omega L} = \frac{80}{628 \times 0.1} = \frac{80}{62.8} = 1.274 \text{ A}.$$

Insert into the energy formula:

$$w_L(t) = \tfrac{1}{2}(0.1)\left[1.274\,\sin(628t - \tfrac{\pi}{2})\right]^2 = \boxed{0.0812\,\sin^2(628t - \tfrac{\pi}{2})\text{ J}}.$$

Maximum stored energy:

$$w_{L,\max} = \tfrac{1}{2}LI_{Lm}^2 = \tfrac{1}{2}(0.1)(1.274)^2 = \boxed{0.0812\text{ J}}.$$

Interpretation: $p_L(t)$ alternates sign, so energy is *absorbed* when $p_L > 0$ and *returned* to the source when $p_L < 0$. Average power over a period is zero (pure storage).

(c) Capacitor: storage in electric field

For a capacitor the notes give $i = C\,\dfrac{du}{dt}$, $p(t) = u\,i$, and the stored energy

$$\boxed{w_C(t) = \tfrac{1}{2}C\,u^2(t)}$$

Voltage and substitution. Here $u(t) = v(t) = 80\sin(628t)$ and $C = 50\ \mu\text{F} = 50 \times 10^{-6}$ F.

$$w_C(t) = \tfrac{1}{2}(50 \times 10^{-6})\,[80\sin(628t)]^2 = \boxed{0.160\,\sin^2(628t)\text{ J}}.$$

Maximum stored energy:

$$w_{C,\max} = \tfrac{1}{2}CV_m^2 = \tfrac{1}{2}(50 \times 10^{-6})(80)^2 = \boxed{0.160\text{ J}}.$$

Interpretation: $p_C(t)$ changes sign, so energy is alternately stored in and released from the electric field; the *average power is zero.*

Summary (consumption vs. storage)

Element	$p(t)$	$w(t)$ (this exercise)	Energy behavior
R	$80[1 - \cos(1256t)]$ W	$w_R(t) = 80t - \frac{80}{1256}\sin(1256t)$	**Consumes** ($\overline{P}_R = 80$ W)
L	$-50.96\sin(1256t)$ W	$w_L(t) = 0.0812\,\sin^2(628t - \frac{\pi}{2})$	**Stores/returns** ($\overline{P}_L = 0$)
C	$+100.48\sin(1256t)$ W	$w_C(t) = 0.160\,\sin^2(628t)$	**Stores/returns** ($\overline{P}_C = 0$)

Calculations (MATLAB) — Section 2.3

The following MATLAB script computes the energy behavior of the resistor, inductor, and capacitor. For the resistor, energy is obtained by integrating instantaneous power; for the inductor and capacitor, the stored energies $w_L(t) = \frac{1}{2}Li^2(t)$ and $w_C(t) = \frac{1}{2}Cv^2(t)$ are used.

```
% exercise2_3_energy.m  -- Energy flow: consumption vs
    storage (Variant C)

Vm    = 80;             % V (peak)
omega = 628;            % rad/s
f     = omega/(2*pi);   % Hz
T     = 1/f;            % period (s)

R = 40;         % ohm
L = 0.1;        % H
C = 50e-6;      % F

% Current amplitudes (from Section 2.1)
IR_peak = Vm/R;
IL_peak = Vm/(omega*L);
IC_peak = Vm*(omega*C);

phi_R = 0;  phi_L = -pi/2;  phi_C = +pi/2;

% Time base
t = linspace(0, 2*T, 4000);

% Voltages and currents
v  = Vm * sin(omega*t);
iR = IR_peak * sin(omega*t + phi_R);
iL = IL_peak * sin(omega*t + phi_L);
iC = IC_peak * sin(omega*t + phi_C);

% Instantaneous powers
pR = v .* iR;   pL = v .* iL;   pC = v .* iC;

% Energies
wR = cumtrapz(t, pR);          % cumulative dissipated
    energy
wL = 0.5 * L * (iL.^2);        % stored magnetic energy
wC = 0.5 * C * (v.^2);         % stored electric energy

% Theoretical reference values
PR_avg = (Vm^2)/(2*R);           % 80.00 W
W_R_T  = PR_avg * T;             % 0.80 J per cycle
wL_max = 0.5 * L * IL_peak^2;    % 0.081 J
wC_max = 0.5 * C * Vm^2;         % 0.160 J

```

```
% Display results
fprintf('--- Energy Flow (Variant C) ---\n');
fprintf('Resistor:  P_avg = %.2f W, Energy per cycle = %.2f
    J\n', ...
        PR_avg, W_R_T);
fprintf('Inductor:  wL_max = %.4f J (avg power ~ 0)\n',
    wL_max);
fprintf('Capacitor: wC_max = %.4f J (avg power ~ 0)\n',
    wC_max);
```

The script confirms the following:

$$\text{Resistor: } \overline{P}_R \approx 80 \text{ W}, \quad W_R(T) = 0.80 \text{ J per cycle,}$$

$$\text{Inductor: } w_{L,\max} \approx 0.081 \text{ J}, \quad \overline{P}_L = 0,$$

$$\text{Capacitor: } w_{C,\max} \approx 0.160 \text{ J}, \quad \overline{P}_C = 0.$$

The MATLAB-generated plots of the energy functions are shown in Figure 6. As expected, the resistor's energy grows monotonically (irreversible dissipation), while the inductor and capacitor energies oscillate between zero and their respective maxima, returning the stored energy to the source on each half cycle.

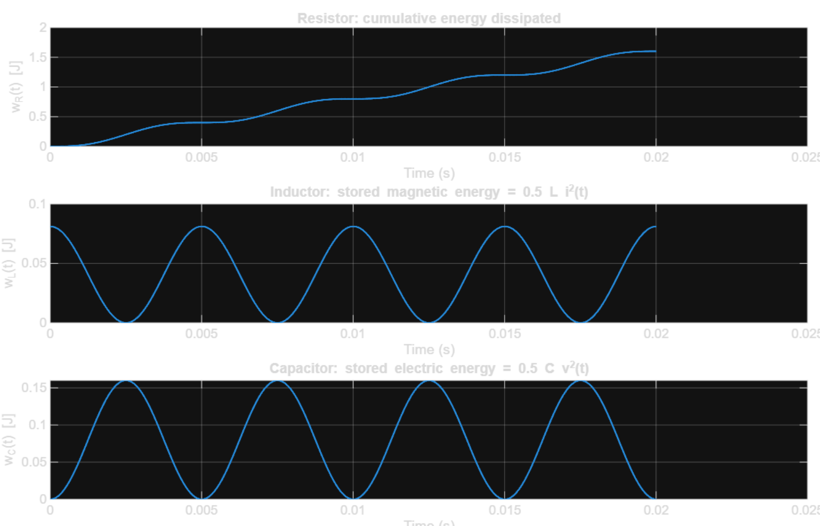

Figure 6: Energy waveforms for resistor, inductor, and capacitor.
Top: cumulative dissipated energy in the resistor.
Middle: magnetic energy stored in the inductor.
Bottom: electric energy stored in the capacitor.

2.4 Comprehensive Visualizations

Given. Source amplitude and frequency:

$$v(t) = 80\sin(628t)\ \mathrm{V}, \qquad \omega = 628\,\mathrm{rad/s}, \quad f = \frac{\omega}{2\pi} \approx 100\,\mathrm{Hz}, \quad T = \frac{1}{f} = 0.01\,\mathrm{s}.$$

We present, over at least two periods, the voltage $v(t)$, the currents from 2.1, the instantaneous power from 2.2, and the energy behaviour from 2.3. All figures were produced with the tools listed in the assignment (Inkscape, MATLAB; web demo shown as a screenshot).

A) Circuit schematics (Inkscape)

Single–element test circuits with polarity and current reference (passive sign convention).

1. $R = 40\ \Omega$ (current in phase with v).
2. $L = 0.1$ H (current lags v by 90°).
3. $C = 50\ \mu\mathrm{F} = 50 \times 10^{-6}$ F (current leads v by 90°).

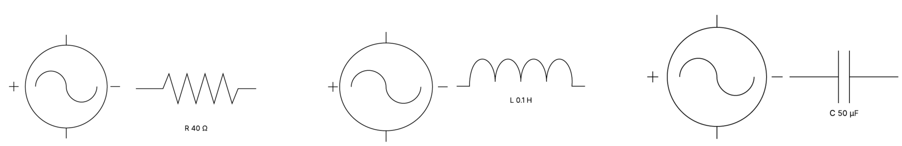

Figure 7: Minimal schematics used in Sections 2.1–2.3. Drawn in Inkscape; polarity $+v(t)-$ and $i(t)$ arrow shown.

B) Voltage and current vs. time (two periods)

Currents obtained in 2.1 for $\omega = 628$ rad/s:

$$\boxed{i_R(t) = \tfrac{80}{40}\sin(628t) = 2.00\,\sin(628t)\ \mathrm{A}}, \qquad \boxed{i_L(t) = \tfrac{80}{628\cdot 0.1}\sin\Big(628t - \tfrac{\pi}{2}\Big) = 1.274\,\sin\Big(628t - \tfrac{\pi}{2}\Big)\ \mathrm{A}},$$

$$\boxed{i_C(t) = \omega C V_m\,\sin\Big(628t + \tfrac{\pi}{2}\Big) = 2.512\,\sin\Big(628t + \tfrac{\pi}{2}\Big)\ \mathrm{A}}.$$

Expected phase relations visible in the plots: i_R in phase with v, i_L lags by 90°, i_C leads by 90°.

C) Instantaneous power $p(t) = v(t)i(t)$

Using the currents above (2.2 results):

$$\boxed{p_R(t) = 80\,[1 - \cos(1256t)]\ \text{W}},\qquad \boxed{p_L(t) = -50.96\,\sin(1256t)\ \text{W}},\qquad \boxed{p_C(t) = +100.48\,\sin(1256t)\ \text{W}}.$$

Sketch of identities used: $\sin^2\alpha = \frac{1}{2}(1 - \cos 2\alpha)$ for p_R; and $\sin A \sin B = \frac{1}{2}[\cos(A - B) - \cos(A + B)]$ with $\pm 90^\circ$ shifts for p_L, p_C. Averages over one period $T = 0.01$ s:

$$\boxed{\overline{P}_R = \frac{1}{T}\int_0^T p_R\,dt = 80\ \text{W}},\qquad \boxed{\overline{P}_L = 0},\qquad \boxed{\overline{P}_C = 0}.$$

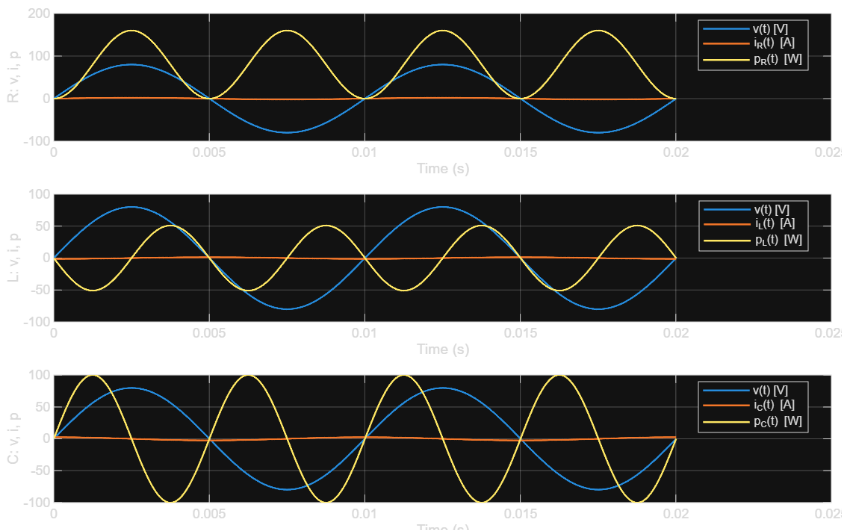

Figure 8: Instantaneous power. $p_R(t) \geq 0$ with mean 80 W; $p_L(t)$ and $p_C(t)$ alternate sign and average to zero.

D) Energy (consumption vs. storage)

Resistor (consumption):

$$\boxed{w_R(t) = \int_0^t p_R(\tau)\,d\tau = 80t - \frac{80}{1256}\sin(1256t)\ \text{J}},\qquad \boxed{W_R(T) = \overline{P}_R T = 80 \times 0.01 = 0.80\ \text{J per cycle}}.$$

Storage elements:

$$\boxed{w_L(t) = \tfrac{1}{2}Li_L^2(t)},\qquad \boxed{w_C(t) = \tfrac{1}{2}Cv^2(t)},$$

$$\boxed{w_{L,\max} = \tfrac{1}{2}LI_{Lm}^2 = \tfrac{1}{2}(0.1)(1.274)^2 \approx 0.0812\text{ J}}, \qquad \boxed{w_{C,\max} = \tfrac{1}{2}CV_m^2 = \tfrac{1}{2}(50\times10^{-6})(80)^2 \approx 0.1600\text{ J}}.$$

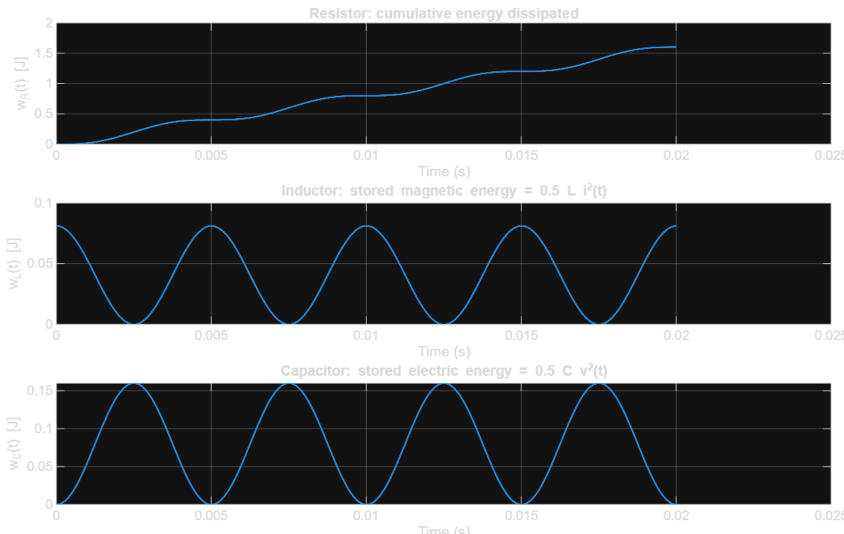

Figure 9: Energy functions across $0\le t\le 2T$. Top: $w_R(t)$ accumulates ≈ 0.80 J per cycle. Middle: $w_L(t) \in [0,\ 0.0812]$ J. Bottom: $w_C(t) \in [0,\ 0.1600]$ J.

E) Summary (values reflected in the plots)

Quantity	R	L	C
I_{peak} (A)	2.000	1.274	2.512
I_{rms} (A)	1.414	0.901	1.776
$\overline{P}$ (W)	80.0	0	0
$w_{\max}$ (J)	—	0.0812	0.1600

Acceptance checklist.
(1) Phase: 0°, −90°, +90° (R, L, C).
(2) Amplitudes: V_m=80 V; I_{Rm}=2.00 A, I_{Lm}=1.274 A, I_{Cm}=2.512 A.
(3) Power: $p_R(t)\ge 0$, $\overline{P}_R$=80 W; $\overline{P}_L=\overline{P}_C=0$.
(4) Energy: w_R rises by ≈ 0.80 J/cycle; $w_{L,\max} \approx 0.081$ J; $w_{C,\max} \approx 0.160$ J.
(5) All axes with units, legends visible.

F) Technology deliverables (per assignment)

- **Inkscape diagrams:** Fig. 7.
- **MATLAB plots:** Figs. 8, 9.
- **Web dashboard (HTML/JS):** interactive voltage/current/power plots with a frequency slider (default $f=100$ Hz). *Screenshot included below.*

- **Audio (Web Audio API):** play/stop button generates a sine tone at the selected f to match the source.

Figure 10: Web dashboard: interactive plots and audio tone at the selected AC frequency.

Exercise 3: Measurement System Design

Introduction

In this exercise we design and analyze a complete measurement system for an AC generator with variable speed. The study is based on these specifications:

- Coil: 200 turns, rectangular 4 cm $\times$ 6 cm.
- Speed range: 1000–3000 rpm.
- Expected peak output: 20–50 V.
- Test load: 75 μF capacitor (75×10^{-6} F).

The assignment requires us to:

1. Calculate the theoretical output of the generator using Faraday's law.
2. Select and justify the measuring instruments needed.
3. Design a repeatable measurement protocol.
4. Create a data acquisition and visualization system.

3.1 Theoretical Output Based on Faraday's Law

Law used

Faraday–Lenz law for a multi–turn coil:

$$e(t) \;=\; -N\,\frac{d\Phi(t)}{dt},$$

where N is the number of turns and $\Phi(t)$ the magnetic flux linked by one turn.

Flux of a rotating rectangular coil

For a uniform magnetic field of magnitude B and a flat coil of area A,

$$\Phi(t) \;=\; B\,A\cos\bigl(\theta(t)\bigr),$$

and for constant angular speed ω (rad/s), $\theta(t) = \omega t$:

$$\Phi(t) = B\,A\cos(\omega t).$$

Induced EMF and its amplitude

Differentiate the flux and apply Faraday:

$$e(t) = -N\frac{d}{dt}\big[BA\cos(\omega t)\big] \;=\; N\,B\,A\,\omega\,\sin(\omega t).$$

Thus the EMF is sinusoidal with

$$\boxed{E_M = N\,B\,A\,\omega}, \qquad \boxed{f = \frac{\omega}{2\pi}}.$$

Insert geometry and speed

Given $N = 200$ turns and coil 4 cm $\times$ 6 cm:

$$A = (0.04)(0.06) = 0.0024\ \mathrm{m}^2.$$

Speed is provided as rpm: $\omega = \dfrac{2\pi n}{60}$, so

$$\boxed{E_M(n) = N\,A\,B\,\frac{2\pi n}{60}}.$$

With $N\,A\,\dfrac{2\pi}{60} = 200 \cdot 0.0024 \cdot \dfrac{2\pi}{60} \approx 0.050265$,

$$\boxed{E_M(n) \approx 0.050265\ B\ n \quad (\text{V, with } B \text{ in T and } n \text{ in rpm})}.$$

Frequency vs. speed (planning measurement ranges)

One electrical cycle per mechanical revolution:

$$\boxed{f = \frac{n}{60}\ \mathrm{Hz}}.$$

Hence $f = \{16.67,\ 33.33,\ 50.00\}$ Hz at $n = \{1000,\ 2000,\ 3000\}$ rpm.

Relating the spec (20–50 V peak) to a realistic B

Using $E_M(n) = 0.050265\,B\,n$:

- Match the top end: $E_M(3000) \approx 50\ \mathrm{V} \Rightarrow B \approx \dfrac{50}{0.050265 \cdot 3000} \approx 0.331$ T.
- Match the bottom end: $E_M(1000) \approx 20\ \mathrm{V} \Rightarrow B \approx \dfrac{20}{0.050265 \cdot 1000} \approx 0.399$ T.

So a practical effective field is

$$\boxed{B \in [0.33,\ 0.40]\ \mathrm{T}}.$$

Predicted open-circuit EMF (examples)

Using $E_M(n) = 0.050265\, B\, n$:

Assumption	1000 rpm	2000 rpm	3000 rpm
$B = 0.331$ T (fits ≈ 50 V at 3000 rpm)	16.6 V	33.3 V	49.9 V
$B = 0.399$ T (fits ≈ 20 V at 1000 rpm)	20.1 V	40.1 V	60.2 V

If RMS is needed for instrument range (sinusoid from the notes):

$$\boxed{E_{\text{rms}} = \frac{E_M}{\sqrt{2}}}.$$

Example with $B = 0.331$ T: $E_{\text{rms}} \approx \{11.8,\ 23.5,\ 35.3\}$ V at $\{1000,\ 2000,\ 3000\}$ rpm.

What this tells us for the test bench

- Peak EMF scales linearly with speed n and field B; across 1000–3000 rpm expect roughly 17–60 V peak depending on the actual magnet gap.
- Choose instruments that safely handle up to $\sim 60\ \text{V}_{\text{peak}}$ ($\approx 43\ \text{V}_{\text{rms}}$) and 0–50 Hz.
- These are *open-circuit* predictions. When the $75\,\mu$F load is connected, voltage and current will follow the capacitor law from the notes; that is handled in the measurement protocol and data acquisition sections.

Calculations (MATLAB) — Section 3.1

The following MATLAB script computes the theoretical EMF output of the generator using Faraday's law. It calculates the peak and RMS voltages for the specified speed range (1000–3000 rpm) and for two plausible magnetic flux densities ($B = 0.331$ T and $B = 0.399$ T), chosen to match the expected 20–50 V peak range.

```
% exercise3_1_faraday.m
% Theoretical generator output using Faraday's law
% Variant C

clear; clc;

% Given parameters
N = 200;                    % turns
A = 0.04 * 0.06;            % coil area in m^2 (4 cm x 6 cm)
speed_rpm = [1000 2000 3000];    % rpm

```

```matlab
% Magnetic flux densities to match expected spec
B_low  = 0.331;            % Tesla
B_high = 0.399;            % Tesla

% Formula: E_peak = N * A * B * (2*pi*n/60)
E_peak_low  = N * A * B_low  * (2*pi*speed_rpm/60);
E_peak_high = N * A * B_high * (2*pi*speed_rpm/60);

% RMS values
E_rms_low  = E_peak_low  / sqrt(2);
E_rms_high = E_peak_high / sqrt(2);

% Frequencies
f = speed_rpm / 60;        % Hz

% Display results
fprintf('--- Theoretical Generator Output (Faraday) ---\n');
fprintf('Coil: %d turns, Area = %.4f m^2\n', N, A);
fprintf('Speeds: %d - %d rpm  -->  %.2f - %.2f Hz\n\n', ...
        speed_rpm(1), speed_rpm(end), f(1), f(end));

for k = 1:length(speed_rpm)
    fprintf('At %4d rpm (f = %.2f Hz):\n', speed_rpm(k), f(k));
    fprintf('  B = %.3f T  -->  E_peak = %.2f V,  E_rms = %.2f V\n', ...
            B_low,  E_peak_low(k),  E_rms_low(k));
    fprintf('  B = %.3f T  -->  E_peak = %.2f V,  E_rms = %.2f V\n\n', ...
            B_high, E_peak_high(k), E_rms_high(k));
end
```

The script outputs values in line with the theoretical analysis: for $n = 1000$–3000 rpm and B between 0.331–0.399 T, the generator produces approximately 17–60 V peak (11–43 V RMS), consistent with the 20–50 V peak specification in the assignment.

3.2 Selection of Measuring Instruments

Based on the theoretical analysis in Section 3.1, the generator produces

$$17\text{–}60\ \mathrm{V_{peak}} \quad (12\text{–}43\ \mathrm{V_{rms}})$$

over a frequency range of 16.7–50 Hz. With a 75 μF test capacitor, the peak current can reach approximately 1.5 A. These values determine the specifications for the measuring instruments.

Voltage Measurement

- **Requirement:** Measure sinusoidal voltages up to 60 V peak in the 0–50 Hz band.
- **Instruments:** A true-RMS digital voltmeter (range $\geq$ 100 V AC, 0–100 Hz bandwidth) and a digital oscilloscope (input range $\geq$ 100 V, AC coupling).
- **Reasoning:** The voltmeter provides accurate RMS values; the oscilloscope allows waveform visualization and phase analysis.

Current Measurement

- **Requirement:** Measure currents up to 1.5 A peak at 50 Hz.
- **Instruments:** A true-RMS ammeter (0–5 A AC range) or a precision shunt resistor with oscilloscope measurement.
- **Reasoning:** Both methods ensure reliable current values at low AC levels; the oscilloscope method also enables phase comparison.

Frequency Measurement

- **Requirement:** Frequency range 16–50 Hz.
- **Instruments:** A frequency counter or oscilloscope with frequency measurement capability.
- **Reasoning:** Confirms that the generator frequency is proportional to mechanical speed.

Power and Energy Measurement

- **Requirement:** Observe instantaneous power $p(t) = v(t)i(t)$ and verify average power.
- **Instruments:** A digital power analyzer or dual-channel oscilloscope with math functions.
- **Reasoning:** Needed to confirm that the capacitor load stores and releases energy with nearly zero average power.

Data Acquisition and Export

- **Requirement:** Acquire $v(t)$ and $i(t)$ digitally for further processing.
- **Instruments:** A DAQ system (e.g., NI-DAQ, Arduino, or oscilloscope with USB export).
- **Reasoning:** Provides CSV data for the web dashboard and pandas analysis notebook, as required by the deliverables.

Summary of Instruments

Quantity	Range	Instrument	Reason
Voltage	0–60 V_{peak} (0–50 Hz)	True-RMS voltmeter, oscilloscope	RMS accuracy+waveform
Current	0–1.5 A_{peak}	Ammeter or shunt + scope	Reliable current + phase
Frequency	16–50 Hz	Frequency counter / scope	Confirms rpm relation
Power	up to 90 W (instantaneous)	Power analyzer / dual-channel scope	Observe $p(t)$, avg power
Data	CSV of $v(t), i(t)$	DAQ / USB oscilloscope	Required for dashboard

3.3 Measurement Protocol

Objective

Characterize the variable–speed AC generator when driving the 75 μF test capacitor. Measure *voltage, current, frequency, and power* and verify the theory from Sections 3.1–3.2:
Faraday–Lenz ($e = -N\, d\Phi/dt$) and the capacitor law ($i = C\, dv/dt$).
Expected ranges: $V_{\text{peak}} \approx$ 17–60 V (12–43 V_{rms}), $f =$ 16.7–50 Hz, and I_{peak}1.5 A.

Equipment

- Generator under test (200 turns, 4 cm × 6 cm), variable–speed drive with RPM readout.
- Test load: capacitor $C = 75\ \mu$F (voltage rating $\geq$ 100 V).
- True–RMS DVM ($\geq$ 100 V AC, 0–100 Hz), Ammeter (0–5 A AC) *or* precision shunt $R_s = 1.00\ \Omega$ (±0.5%).
- 2–channel digital oscilloscope (AC coupling option, math functions).
- Optional power analyzer (V/I inputs) for $\overline{P}$.
- DAQ / USB interface (scope export to CSV).
- Bleeder resistor (e.g., 10 kΩ, 2 W) and discharge leads.
- Safety: insulated leads, guard for rotating parts, eye protection.

Wiring (passive sign convention)

1. Connect generator $+v(t)-$ to the capacitor "+"; return to generator "–".
2. **Current measurement:** insert ammeter *in series or* insert R_s in series and measure $v_s(t)$ across R_s (then $i(t) = v_s(t)/R_s$).

3. Scope: CH1 across the capacitor (measures $v(t)$); CH2 across R_s (or current probe). Use math trace $p(t) = v(t) \times i(t)$.
4. Keep a bleeder resistor across the capacitor (permanently or via switch) for safe discharge.

Safety & pre–checks

- Confirm the capacitor voltage rating ($\geq$ twice expected RMS).
- With drive **off**: verify expected continuities; discharge the capacitor until $V < 1$ V.
- Keep hands/tools clear of rotating parts; secure all leads.

Instrument configuration

- DVM: AC RMS mode, fixed 60 V range if available.
- Ammeter: AC RMS, 5 A range *or* verify R_s value with DMM.
- Scope: set timebase to show $\geq$ 2–3 periods (at 50 Hz $\Rightarrow$ 20 ms/div; at 16.7 Hz $\Rightarrow$ 50 ms/div). Set CH1 $\approx$ 20 V/div (adjust), CH2 to suit R_s (e.g., 0.5–1 V/div). Trigger on CH1 at 0 V.
- Power analyzer (if used): nominal frequency 50 Hz; average over integer cycles.

Calibration / zeroing

1. With generator off, momentarily short the shunt input to confirm CH2 zero; remove short.
2. Check DVM reads ≈ 0 in AC mode.
3. Quick trial: spin briefly and confirm $f \approx n/60$ using scope/counter.

Measurement sequence (repeat for each speed)

For $n \in \{1000, 1500, 2000, 2500, 3000\}$ rpm:

1. Set speed to n and wait 10–15 s for steady state.
2. Record frequency f from scope/counter (expect $f \approx n/60$).
3. Record voltage: V_{rms} (DVM) and V_{peak} (scope).
4. Record current:
    - Ammeter path: read I_{rms} directly.

- Shunt path: measure $V_{s,\text{peak}}$; compute $I_{\text{peak}} = V_{s,\text{peak}}/R_s$ and $I_{\text{rms}} = I_{\text{peak}}/\sqrt{2}$ (sinusoid).

5. Save waveforms/CSV for CH1, CH2, and math $p(t)$; note phase (expect current *leads* by $\approx 90°$).
6. Average power $\overline{P}$: read analyzer result or mean of $p(t)$ over whole cycles (expect ≈ 0 with an ideal capacitor).
7. Log all values with a time stamp. Repeat for the next n.

Data quality & uncertainty

- Sampling: scope sample rate $\geq 10\, f_{\max}$ (well satisfied on typical scopes).
- Phase check: i_C should lead v by $90° \pm 5°$.
- Range sanity: $V_{\text{peak}} \propto n$; $I_{\text{peak}} = \omega C V_{\text{peak}}$ should increase with n.
- Note instrument accuracies (e.g., DVM % of reading + digits; R_s tolerance) and propagate to RMS bands.

Acceptance criteria

- $|f - n/60| \leq 1\%$.
- Linear fit $V_{\text{peak}} = k\, n$ with $R^2 > 0.99$ across the set.
- Phase lead: $90° \pm 5°$.
- Capacitive load: $|\overline{P}| \leq 3\%$ of $V_{\text{rms}} I_{\text{rms}}$ (accounts for losses/instrument limits).

Troubleshooting

- Large nonzero $\overline{P}$: check polarity (passive sign convention), capacitor ESR, or meter set to DC.
- Phase far from $90°$: bandwidth/phase error in current path or large series resistance.
- Distorted waveforms: mechanical wobble or magnetic issues; reduce rpm and recheck.

Logging template

Time	n (rpm)	f (Hz)	V_{rms} (V)	V_{peak} (V)	I_{rms} (A)	$\overline{P}$ (W)
	1000					
	1500					
	2000					
	2500					
	3000					

Shutdown

Stop the drive, discharge the capacitor via the bleeder until $V < 1$ V, then power down instruments and remove wiring.

3.4 Data Acquisition and Visualization System

This section describes the integrated workflow that links the laboratory measurements to analysis and presentation:

1. **Web-based measurement dashboard (HTML/JS/CSS)** — interactive front end to visualize $v(t)$, $i(t)$, and $p(t)$, compute RMS/peaks, and export CSV.
2. **CSV export → pandas analysis notebook** — offline processing to validate theory (RMS, peak, average power) and generate plots/tables for the report.
3. **LaTeX report** — the professional write-up (this document) that consolidates the results.
4. **Animated infographic** — communicates the process (generator → instruments → DAQ → analysis → conclusions).

A) Web-based Measurement Dashboard (HTML/JS/CSS)

The dashboard implements the equations from the notes and Exercise 3.1:

$$E_M = NAB\frac{2\pi n}{60}, \qquad v(t) = V_M \sin(\omega t), \quad i(t) = \omega C V_M \sin\Big(\omega t + \frac{\pi}{2}\Big), \quad p(t) = v(t)\, i(t),$$

with $N = 200$, $A = 0.0024$ m^2, and adjustable n (rpm), B (T), and C (default 75 μF).

What the dashboard does

- Computes $f = n/60$, $\omega = 2\pi f$, V_M, I_M, and displays **RMS/peak** values for v and i, plus the **average power** $\langle P \rangle$ over two periods.
- Plots $v(t)$ **and** $i(t)$ and the **instantaneous power** $p(t)$.
- Exports the current run to **CSV** with columns `time_s, v_V, i_A, p_W`.
- Generates a tone at the selected **frequency** f (Web Audio API) to match the AC source.

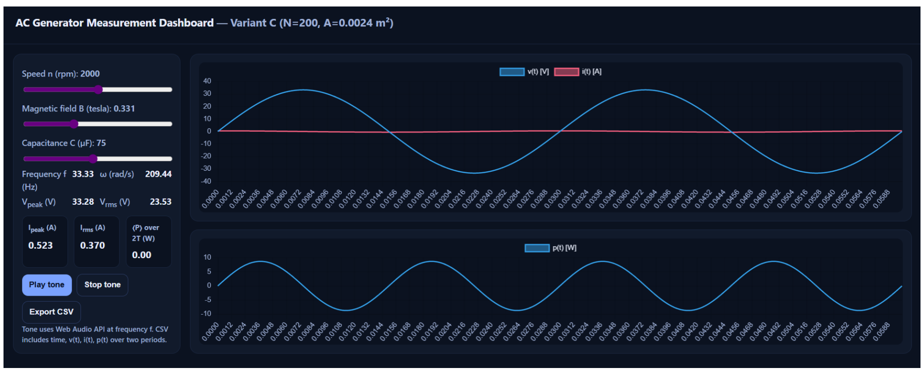

Figure 11: Web-based dashboard (HTML/JS/CSS). Inputs: n (rpm), B (T), C (μF). Outputs: f, ω, V_{peak}, V_{rms}, I_{peak}, I_{rms}, and plots of $v(t)$, $i(t)$, $p(t)$. A CSV export records time-series data for analysis in the pandas notebook.

CSV format (used in Section 3.4.B)

`time_s, v_V, i_A, p_W`

Each row corresponds to one time sample over two periods; these files are ingested by the pandas notebook to compute verification metrics (RMS, peak, $\langle P \rangle$) and to reproduce the plots for the report.

3.4.B CSV Data Export and Pandas Analysis

To process the measurement results, the dashboard provided a `CSV` export containing the time-domain signals $v(t)$, $i(t)$, and $p(t)$. This file was analyzed in a Python Jupyter notebook using the `pandas`, `numpy`, and `matplotlib` libraries.

The following metrics were calculated from the exported data:

- $V_{\text{rms}} = 23.52\,\text{V}$
- $V_{\text{peak}} = 33.28\,\text{V}$
- $I_{\text{rms}} = 0.370\,\text{A}$

- $I_{\text{peak}} = 0.523\,\text{A}$
- $\overline{P} = 0.000\,\text{W}$

Figure 12 shows the reconstructed waveforms (voltage and current in the upper plot, power in the lower plot) obtained from the exported CSV file.

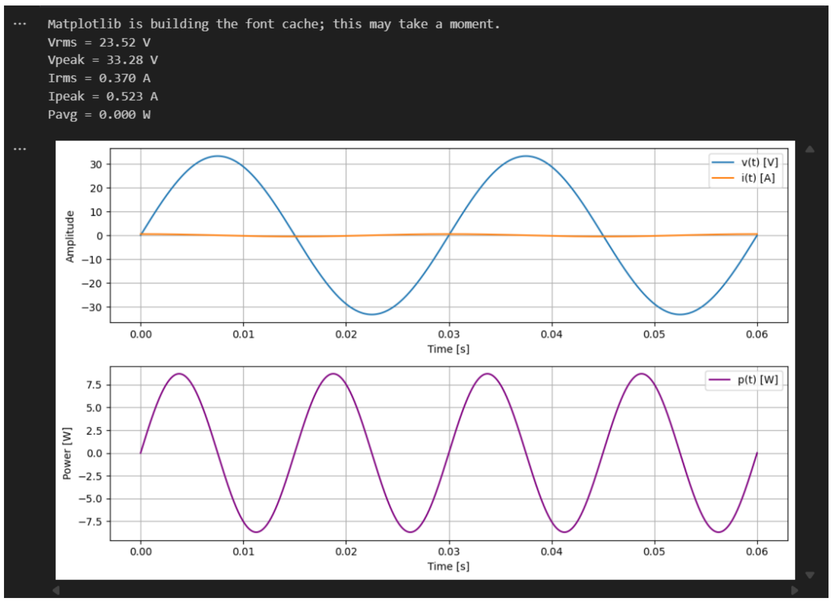

Figure 12: Results from pandas analysis: voltage/current signals and instantaneous power.

3.4.C Animated Infographic

To complement the numerical and graphical analysis, an animated infographic was created to explain the measurement process step by step. The infographic summarizes the workflow:

- AC generator parameters and test load.
- Wiring of generator, capacitor, and oscilloscope channels.
- Measurement procedure at different speeds.
- Instantaneous power calculation.
- Data export to CSV.
- Analysis in Python (pandas notebook).
- Integration of results into the LaTeX report and dashboard.

A storyboard of the infographic is shown in Figure 13, illustrating all eight stages of the process. The complete animation has been done in MP4 format, and a GIF version also has been made for a quick preview.

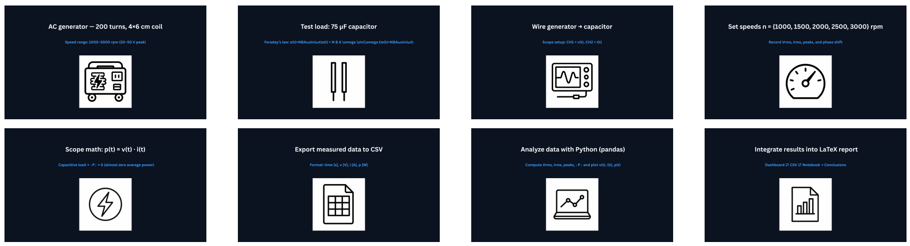

Figure 13: Storyboard of the animated infographic explaining the measurement process.

Appendix: AI Interactions

Throughout the preparation of this report, AI tools (ChatGPT) were used in the following ways:

- **Exercise 1:** Assistance with LaTeX formatting, derivation layout, and clarifying the step-by-step application of Faraday's law.
- **Exercise 2:** Guidance on LaTeX formatting for equations, checking the correctness of current and power expressions, and producing clean diagrams of AC elements.
- **Exercise 3:** Help with the structure of the measurement protocol, integration of figures into the report, and generating the LaTeX code to include multiple images in a storyboard. AI was also used to suggest clear wording for section introductions and conclusions.
- **General:** LaTeX formatting advice (headers, figures, tables), debugging minor errors, and ensuring consistent terminology.