Problem 4.3:
Consider a three-phase permanent magnet synchronous motor with \( n_p = 2 \).
(a) What mechanical resolution can be achieved by combining the line-line and line-2 line stepping modes of open-loop positioning?
(b) What is the frequency of the sinusoidal currents that need to be applied so that the speed is 240 rpm?
(c) At 240 rpm, what is the rms voltage of the back-emf induced on a winding if \( K = 0.046 V.s \)?
(d) At what speed does the back-emf voltage on a winding reach a peak voltage magnitude of 25 V?
(e) In the same condition as part (c), what is the rms value of the sinusoidal currents needed to produce a torque equal to 0.013 N.m, if quadrature control with sinusoidal commutation is used?
(f) In the same condition as part (e), what electrical power is converted to mechanical power (check using the voltages and currents as well as using the torque)?
(g) In the same condition as part (f), what electrical power is absorbed by the motor if the winding resistance is \( R = 0.9 \Omega \)?

Problem 4.4:
(a) Consider a three-phase permanent magnet synchronous motor connected in a line-2 line configuration so that \( v = v_A - v_B = v_A - v_C \) and the current \( i = i_A = -(i_B + i_C) \). Using the line model, show that the motor is equivalent to the connection of a resistor, inductor, and AC source in series, and give the values of the three components.
(b) Given that \( i_B + i_C = -i \), the currents in windings B and C each carry a current \( -i/2 \) plus a circulating current \( \delta i \) such that
\[
\begin{align*}
i_B &= -\frac{i}{2} + \delta i, \\
i_C &= -\frac{i}{2} - \delta i
\end{align*}
\]
Show that \( \delta i \) satisfies a differential equation that is independent of \( v \) and \( i \). Further, observe that \( i_B = i_C = -i/2 \) at zero speed.

Problem 4.5:
(a) Consider a three-phase permanent magnet synchronous motor connected to a source through a line-line connection so that \( i_A = 0 \), \( i_B = I \), \( i_C = -I \). Compute the torque as a function of the angle \( \theta \). Deduce the values of the average torque, minimum torque, and maximum torque in a 6-step commutation scheme. Also compute the peak-peak torque ripple as a percentage of the average torque.
(b) Consider the same motor with a line-2 line connection and assume that \( i_A = I \), \( i_B = -I/2 \), \( i_C = -I/2 \). Compute the torque as a function of the angle \( \theta \). Over what range of \( n_p \theta \) would a line-2
line 6-step commutation scheme use the connection $A \rightarrow B\&C$? What significant change would be applied to a line-2 line 6-step commutation scheme, compared to the line-line configuration? Deduce the values of the average torque, minimum torque, and maximum torque in this alternate 6-step commutation scheme. Also compute the peak-peak torque ripple as a percentage of the average torque.

(c) Compare the results of the line-line and line-2 line connections if a current source is used (the same current $I$ is applied in the two cases) and if a voltage source is used (the same voltage is applied in the two cases). In the second case, assume that the speed is small so that the current in a winding is solely determined by its resistance and the voltage applied.