**Problem No.1: (15 points)**

For a **6-pole, 60 Hz, 5 hp** synchronous motor, with parameters $R_s = 0.05 \Omega$, $X_s = 0.22 \Omega$,

a) What is the no-load speed of the motor?  
b) What is the full-load speed of the motor?  
c) What is the motor speed at 50% load?

**SOLUTION:**

The synchronous motor runs at synchronous speed under any load.

$$n_{sync} = \frac{120 f_e}{P} = \frac{120 \times 60}{6} = 1200 \text{ rpm}$$

**Problem No.2: (15 points)**

An induction machine rated **240V, 4-pole, 60 Hz** is running at **1900 rpm**. The machine parameters are given as follows:

$R_1 = 0.04 \Omega$, $X_1 = 0.1 \Omega$, $R'_2 = 0.03 \Omega$, $X'_2 = 0.08 \Omega$

Is the machine operating as a generator or motor? **Justify your answer.**

**SOLUTION:**

The synchronous speed is $n_{sync} = \frac{120 f_e}{P} = \frac{120 \times 60}{4} = 1800 \text{ rpm}$

$$n_m = 1900 \text{ rpm} > n_{sync},$$

so the machine is operating as a generator.
Problem No.3: (30 points)

A 3-φ, 8-pole, 60 Hz, 440V, Y-connected induction motor has the following parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>0.08Ω/φ (ohm per phase)</td>
</tr>
<tr>
<td>$R_2$</td>
<td>0.07Ω/φ (ohm per phase)</td>
</tr>
<tr>
<td>$X_1$</td>
<td>0.2Ω/φ (ohm per phase)</td>
</tr>
<tr>
<td>$X_2$</td>
<td>0.17Ω/φ (ohm per phase)</td>
</tr>
</tbody>
</table>

The motor is connected to an infinite bus and is running at $s = 5\%$. What is the active and reactive power supplied by the infinite bus at rated voltage?

SOLUTION:

\[
V_φ = \frac{440}{\sqrt{3}} = 254.03\angle0 \text{ V}
\]

\[
I_A = \frac{V_φ}{R_1 + jX_1 + \frac{R_2}{s} + jX_2} = \frac{254.03\angle0}{0.08 + j0.2 + \frac{0.07}{0.05} + j0.17}
\]

\[
= 161.55 - j40.39 = 166.52\angle-14° \text{ A}
\]

\[
S_φ = V_φI_A^* = 254.03\angle0 \times (166.52\angle-14°)^* = 41.04 + j10.26 \text{ kVA}
\]

\[
S_3φ = 3S_φ = 123.12 + j30.78 \text{ kVA}
\]

So the active power supplied by the infinite bus is 123.12 kW. And the reactive power supplied by the infinite bus is 30.78 kVar.
Problem No.4: (30 points)

A 208-V, Y-connected synchronous motor is drawing 100A at unity power factor from a 208-V infinite bus. The field current flowing under these conditions is 2A. Its synchronous reactance is 0.4 Ω (Neglect the armature resistance). Assume a linear open-circuit characteristic. How much field current would be required to make the motor operate at 0.8 PF leading?

SOLUTION:

For synchronous motor: \( E_A = V_\phi - jX_s I_A \)

\[ V_\phi = \frac{208}{\sqrt{3}} = 120 \angle 0 \text{ V} \]

Case 1: unity power factor

\[ I_{A1} = 100 \angle 0 \text{ A} \]

\[ E_{A1} = V_\phi - jX_s I_{A1} = 120 \angle 0 - j0.4 \times 100 \angle 0 = 120 - j40 = 126.5 \angle -18.4^\circ \text{ V} \]

Case 2: 0.8 PF leading

\[ |I_{A1}| \cos \theta_1 = |I_{A2}| \cos \theta_2 \Rightarrow |I_{A2}| = \frac{|I_{A1}| \cos \theta_1}{\cos \theta_2} = 100 \times 1/0.8 = 125 \text{ A} \]

so

\[ I_{A2} = 125 \angle \cos^{-1}(0.8) = 125 \angle 36.87^\circ \text{ A} \]

\[ E_{A2} = V_\phi - jX_s I_{A2} = 120 \angle 0 - j0.4 \times 125 \angle 36.87^\circ = 150 - j40 = 155.2 \angle -14.9^\circ \text{ V} \]

A linear open-circuit characteristic \( E_A \propto I_F \), so

\[ I_{F2} = \frac{|E_{A2}|}{|E_{A1}|} I_{F1} = \frac{155.2}{126.5} \times 2 = 2.45 \text{ A} \]

Problem No.5: (10 points)

A synchronous motor rated 208V, 5 hp, is operating with a power factor of 0.8 leading. The parameters are: \( R_a = 0.05\Omega \) and \( X_s = 0.2\Omega \). It

a) supplies active power and reactive power.

b) supplies active power and consumes reactive power.

c) **consumes active power and supplies reactive power**

d) consumes active power and reactive power.