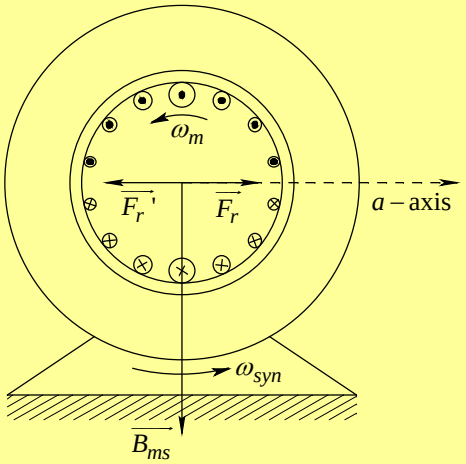
Induction Motors:
Balanced, Sinusoidal Steady State Operation

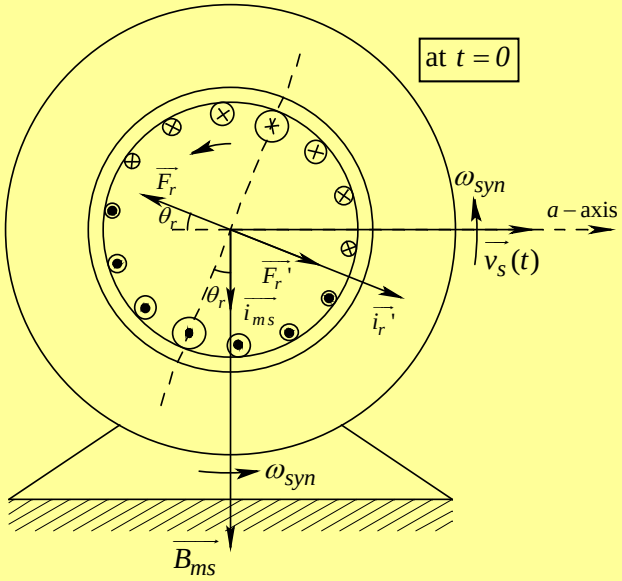
- Generator Operation
- Including Rotor Leakage Inductance
- Per-Phase Equivalent Circuit
- Determining Equivalent Circuit parameters

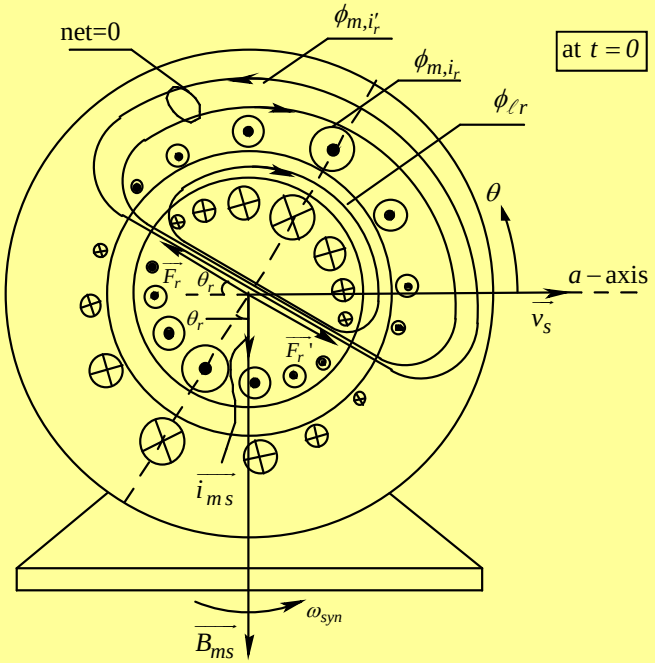
Generator (Regenerative Braking) Mode

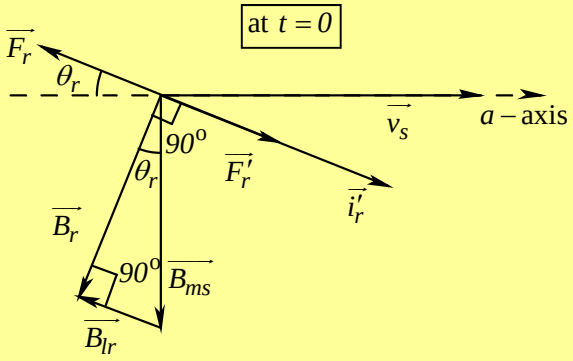


- For generation or for braking – in either case rotor speed exceeds synchronous speed, $\omega_m > \omega_{syn}$
- $\omega_{slip} < 0$
- Bar voltage polarities reversed
- Rotor currents and mmf reversed
- Reflected rotor currents and mmf reversed
- Torque reversed

Rotor Leakage Inductance



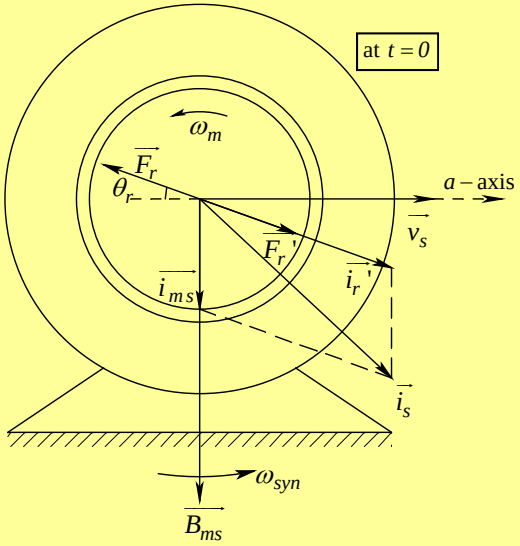




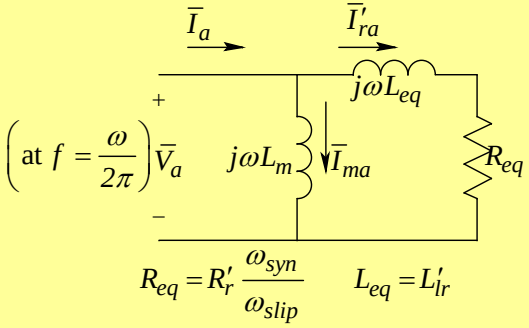
Rotor Leakage Inductance (cont…)

- Effect of rotor leakage inductance is to reduce T_{em} at high slip
- Rotor leakage inductance is often neglected when motor is operating near synchronous speed (below the rated torque)

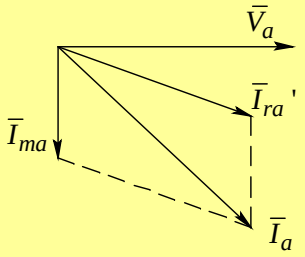
Per-Phase Equivalent Circuit



Space Vectors



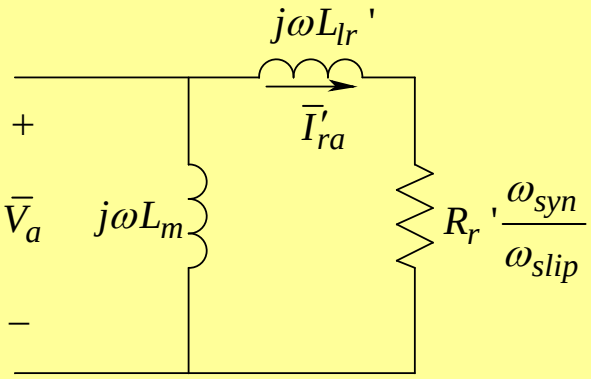
Equivalent Circuit



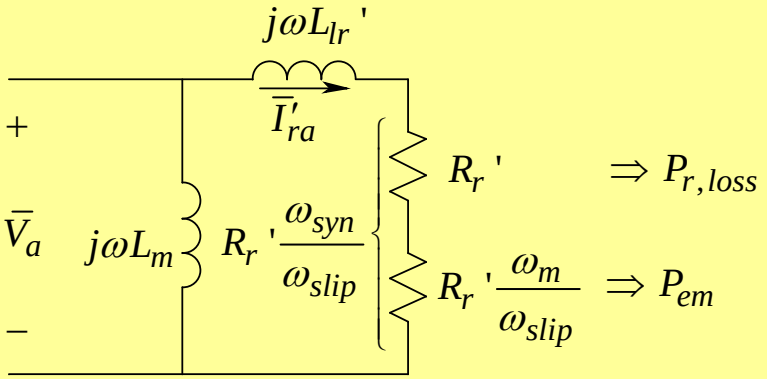
Phasor Diagram

- Includes rotor leakage inductance
- Does not include stator leakage inductance or resistance
- R_{eq} depends on slip

Power Into Rotor – Power Lost In Rotor – Power Out Of Rotor



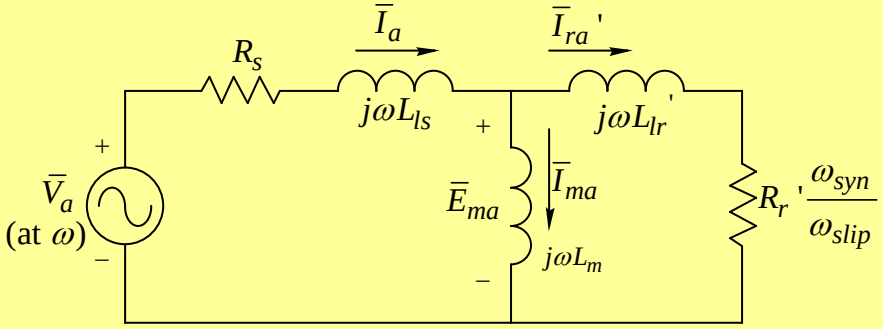
Power in resistor is power into the rotor circuit



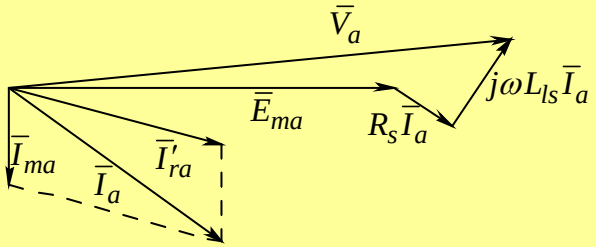
Resistor split to indicate rotor loss and mechanical power

- Power in equivalent resistance represents power entering rotor across air gap
- Depending on slip, some or all of this power becomes losses in the rotor

Stator Winding Resistance and Leakage Inductance



Equivalent Circuit

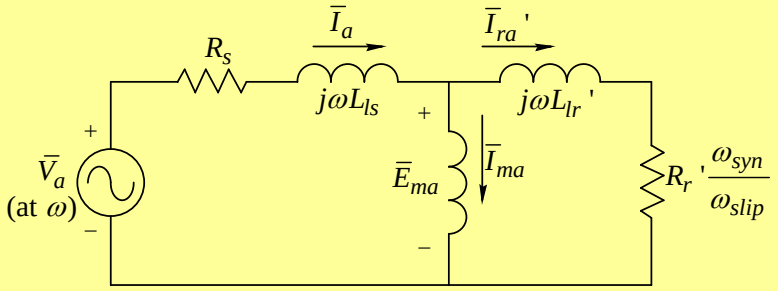


Phasor Diagram

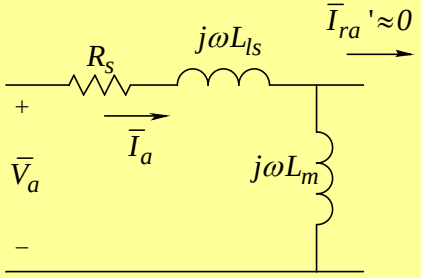
Motor Tests

- DC – Resistance Test (R_s)
- No Load Test (L_m)
- Blocked Rotor Test (R_r', L_{ls}, L_{lr}')

No Load Test (L_m)

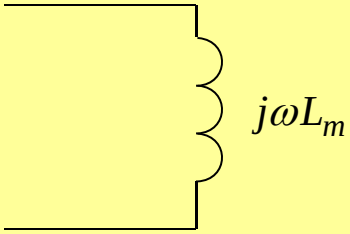


Equivalent Circuit



Equivalent Circuit under no load conditions

($\omega_{slip} = 0 \therefore R_{eq} = \infty$)

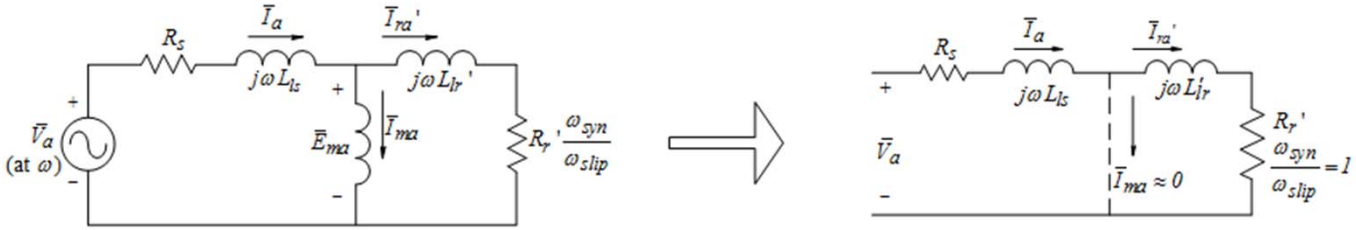


Approximate Circuit

($L_m >> L_l$) (R_s negligible)

- Under no load conditions the equivalent circuit is dominated by the magnetizing inductance

Blocked Rotor Test (L_l)



Equivalent Circuit

Approximate Circuit With Rotor Blocked
$(R_{eq} << \omega L_m)$ and $(\omega L_{\ell r} << \omega L_m)$

- With the rotor blocked, the magnetizing inductance is nearly shorted out and can be neglected
- Measurements give real power (into R_s and R_r') and reactive power (into L_{ls} and L_{lr}')
- R_r' can be found since R_s was previously determined through the DC test
- To find L_{ls} and L_{lr}' we can often assume that $L_{ls} = \frac{2}{3} L_{lr}'$

Summary

- Generator Operation
- Including Rotor Leakage Inductance
- Per-Phase Equivalent Circuit
- Determining Equivalent Circuit parameters