Lesson 16: Asynchronous Generators/Induction Generators

ET 332b

Ac Motors, Generators and Power Systems

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Learning Objectives

After this presentation you will be able to:

- Explain how an induction generator operates
- List application for induction generators in the use renewable resources
- Discuss the limitations of induction generators
- Compute the power developed from an induction generator using the per phase circuit model

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Induction Generators

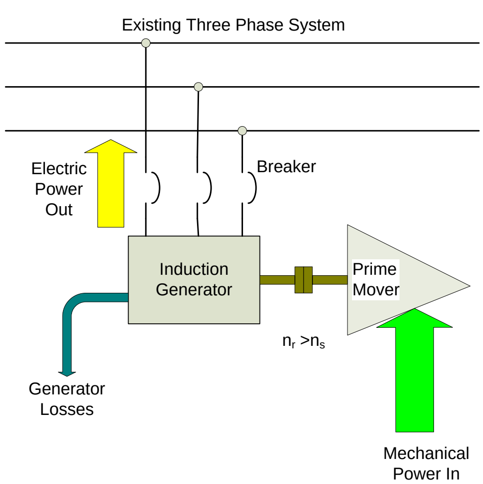
Driving an induction motor faster than synchronous speed when connected to the grid results in active power generation

Induction generators (asynchronous generators) designed with lower rotor R to reduce losses and machine slip.

Applications: Wind Turbines, Hydraulic Turbines (small scale hydro), Gas engines fueled by natural gas or biogas

cogeneration

Induction Generator Starting Sequence

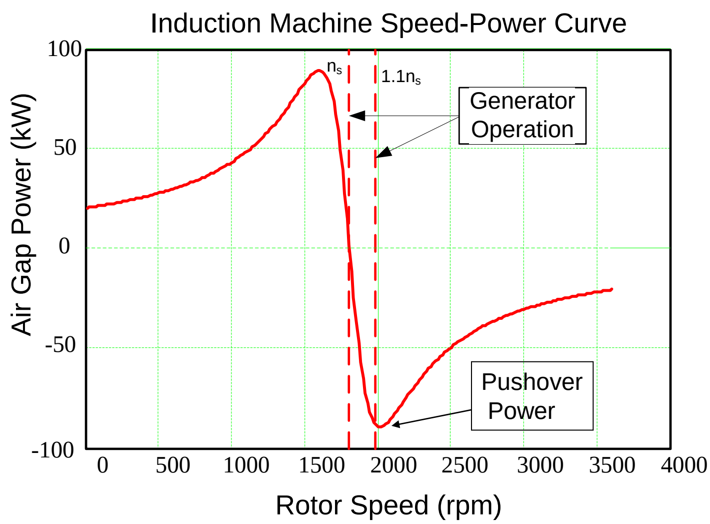


1.) Breaker open
2.) Increase prime mover mechanical power input until $n_r > n_s$.
3.) Close Breaker
4.) Adjust mechanical power input to match electric load.

$P_{mech} = P_e + P_{loss}$

Induction generator can not vary terminal voltage or frequency. Set by system.

Induction Generator Speed Power Curves



Limitations of Induction Generations

- Require existing power grid for synchronous operation.
  - Can not control frequency or voltage independently
- Can not operate above pushover speed
- Require a source of reactive power to operate
  - When connect to grid, system supplies reactive power to operate generator
- When operating without grid connection frequency varies with power output.
  - Parallel capacitors supply reactive power

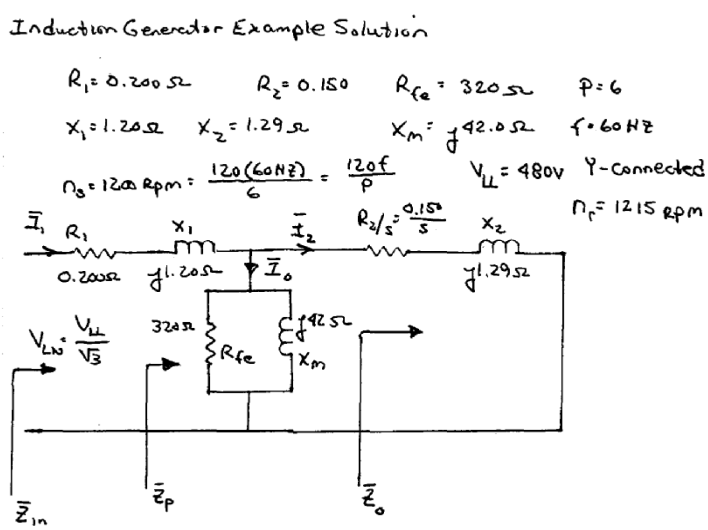
Induction Generator Example

A three-phase, six-pole, 460 V, 60 Hz induction generator operates on a 480 V system. The generator its rated power output is 20 kW. It is driven by a turbine at a speed of 1215 rpm. The generator has the following electrical parameters:

R_1 =0.200 Ω, R_2= 0.150 Ω, R_{fe}= 320 Ω,
X_1=1.20 Ω, X_2=1.29 Ω, X_M=42.0 Ω

Find the active power delivered by the generator and the reactive power it requires from the system to operate.

Example Solution



Example Solution

Find slip $s = \frac{n_s - n_r}{n_s} = \frac{(1200-1215)\text{ rpm}}{1200\text{ rpm}} = -0.0125$

$$\bar{Z}_o = \frac{0.150\,\Omega}{-0.0125} + j1.29\,\Omega = -12 + j1.29\,\Omega = 12.07\angle 173.9^\circ\,\Omega$$

$$\bar{Y}_p = \frac{1}{R_{fe}} + \frac{1}{\bar{X}_m} + \frac{1}{\bar{Z}_o} = \frac{1}{320\,\Omega} + \frac{1}{42\angle 90^\circ} + \frac{1}{12.07\angle 173.9^\circ}$$

$$\bar{Y}_p = 3.125\times10^{-3}\,S + 2.381\times10^{-2}\angle -90^\circ\,S + 8.285\times10^{-2}\angle -173.9^\circ\,S$$

$$\bar{Y}_p = 3.125\times10^{-3} - 2.381\times10^{-2}j - 8.238\times10^{-2} - 8.804\times10^{-3}j\,S$$

$$\bar{Y}_p = -7.926\times10^{-2} - 3.261\times10^{-2}j = 8.571\times10^{-2}\angle -157.6^\circ\,S \qquad \bar{Z}_p = \frac{1}{\bar{Y}_p} = 11.67\angle 157.6^\circ\,\Omega$$

Example Solution

$$\bar{Z}_{in} = (R_1 + jX_1) + \bar{Z}_p = (0.200 + j1.20\,\Omega) + 11.67\angle 157.6^\circ\,\Omega$$

$$\bar{Z}_{in} = (0.200 + j1.20) + (-10.79 + j4.45\,\Omega) = -10.59 + j5.65\,\Omega = 12.\angle 151.9^\circ$$

$$\bar{I}_1 = \frac{\bar{V}_{LN}}{\bar{Z}_{in}} \qquad \bar{V}_{LN} = \frac{480\angle 0^\circ}{\sqrt{3}} = 277.1\,V\angle 0^\circ$$

$$\bar{I}_1 = \frac{277.1\angle 0^\circ}{12\angle 151.9^\circ} = 23.1\angle -151.9^\circ\,A$$

Line Current = Phase current in Y Connected machines.

Find Total Terminal power From phase quantities

$$\bar{S}_T = 3\bar{V}_{LN}\bar{I}_1^*$$

Example Solution

$$\bar{S}_T = 3\bar{V}_{LN}\bar{I}_1^*$$

$$\bar{S}_T = 3(277.1\angle 0^\circ)(23.1\angle -151.9^\circ)^*$$

$$\bar{S}_T = 3(277.1\angle 0^\circ)(23.1\angle 151.9)$$

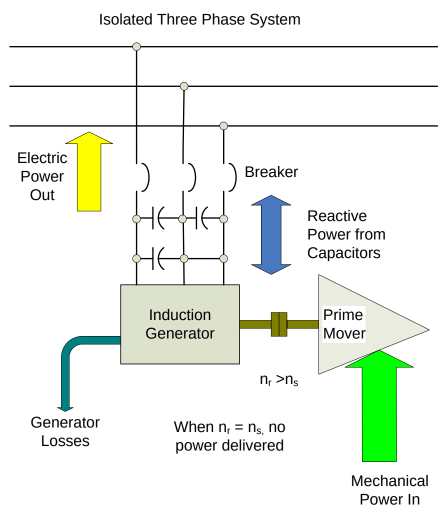
$$\bar{S}_T = 19203\angle 151.9^\circ$$

$$\bar{S}_T = -16{,}940 + j9045$$

Generated Active P: $P = -16{,}940$ watts (Neg indicates power delivered)

$Q = 9045$ VARs (System must supply these VARs for generator to operate)

Isolated Operation of Induction Generators

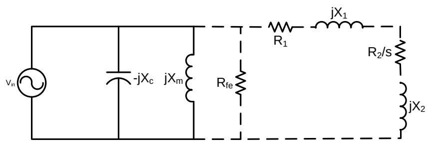


Isolated Induction generator requires residual flux to build voltage

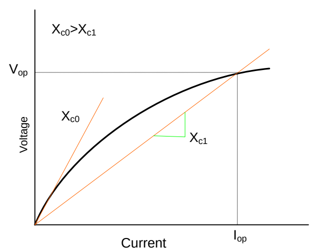
Capacitors supply reactive power to load and generator when voltage builds.

Voltage falls rapidly when load is applied.

Voltage Build-up in Isolated Induction Generators



External Capacitor provides Reactive power for operation



Operating point set by intersection between magnetization curve and X_c

$$|X_c| = \frac{V_{op}}{I_{op}}$$

$$C = \frac{I_{op}}{V_{op}} \cdot \left(\frac{1}{2\pi f}\right)$$

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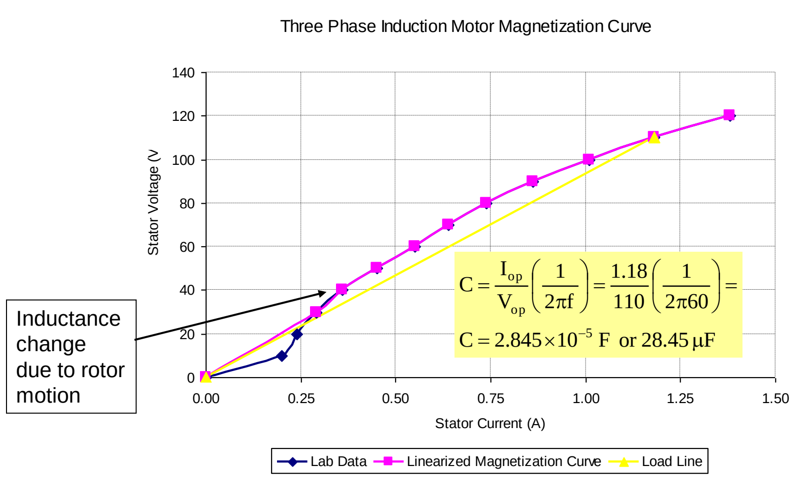
Voltage Build-up in Isolated Induction Generators

Lab measurements determine the magnetization curve



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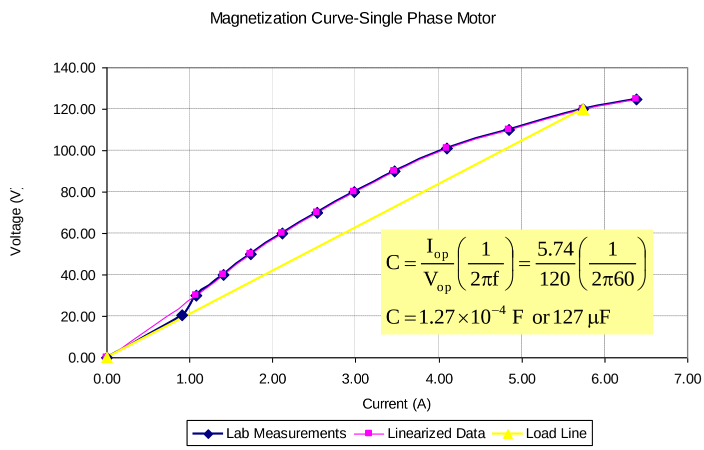
Voltage Build-up in Isolated Induction Generators

Single phase motor magnetization curve



$$C = \frac{I_{op}}{V_{op}}\left(\frac{1}{2\pi f}\right) = \frac{5.74}{120}\left(\frac{1}{2\pi 60}\right)$$

$$C = 1.27 \times 10^{-4}\ \text{F} \text{ or } 127\ \mu\text{F}$$

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END LESSON 16: ASYNCHRONOUS GENERATORS/INDUCTION GENERATORS