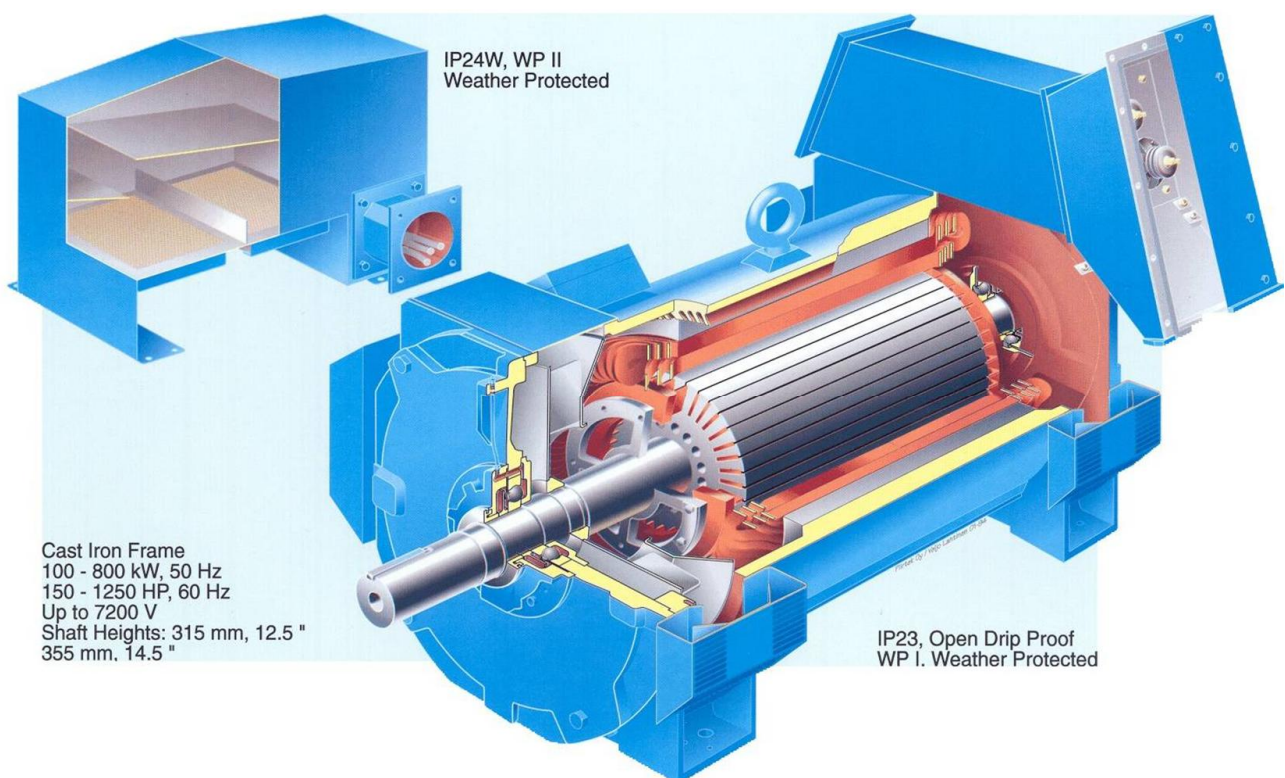


ELEC-E8407 Electromechanics

Laboratory exercise 2:

Induction machines in generator and motor operation



Purpose of the assignment

The purpose of this laboratory work is to understand the basics of the induction machine operations. We consider the induction machine as an independent generator and in a rigid network and investigate the operation of the machine in motoring mode.

It is highly recommended that students are familiar with the speed-torque curve, the characteristics curves, and the generator operation as well as the frequency-converter operation of the machine. The calculation problems are very useful when compiling the preliminary report.

Preliminary report

Answer the following questions and write your individual answers using a computer program (word or equivalent) then return it as a pdf-file within the deadline to the corresponding assignment rubric in MyCourses information system.

1. What are the frequencies of the stator and rotor currents in a four-pole, three-phase induction generator connected to an infinite bus, when the network frequency is $f = 50$ Hz and the rotor speed $n = 1560$ rpm? What is the speed of the air-gap field?
2. The induction machine consumes reactive power both at motoring and generating operation mode. From where does an independent (not connect to the grid) induction generator could receive the reactive power it requires?
3. A squirrel-cage induction machine operates as an independent generator. A capacitance bank of $C = 64 \mu\text{F}$ per phase is connected in star at its terminals. At start-up, the generator is rotated at a speed of $n = 1000$ rpm, whereupon the phase voltage “jumps” to $U_v = 155$ V. What is the magnitude of the voltage when the capacitances are connected in a delta? and at what speed does the excitation occur. Please note that the line excitation current for the star and delta connected capacitor banks remains constant. See the calculation examples at the end of these instructions.
4. How do the maximum torque and the corresponding slip of an induction machine change when it is supplied from a frequency converter in the constant flux region? Assume the stator resistance negligible ($R_s = 0$).

Measurements

Carry out the following measurements under the assistant supervision. Take notes and save data as necessary to make the final report.

1. Measure the efficiency and the power factor of the induction generator when it is connected to an infinite bus. Make the measurement for different output electric power ($I = I_0 \dots 1.2I_N$).
2. Use a vector analyzer to study the voltage, and flux vectors of the stator of the induction machine connected to an infinite bus.
3. Measure the speed-torque curves, the current, and the power factor of the induction motor connected to the infinite bus by ramping the speed down from 1500 rpm to 0 rpm and ramping it up back to 1500 rpm.
4. Measure the no-load voltage of an independent generator, as a function of the speed. Make the measurements with different capacitors.
5. Measure the dependence on the load ($\cos\varphi = 1$) of the efficiency, voltage, current, and frequency of the independent generator running at constant speed. Choose the capacitors so that $U(P_N, f_N) \approx U_N$.
6. Use a vector analyzer to study the stator's voltage, and flux vectors on an induction machine supplied from a frequency converter.

Final report

Use your notes and data from the measurements to make the final report by answering the following questions. Make the final report using a computer program (word or similar) then return the report within the deadline (one report per group) to the corresponding assignment rubric in MyCourses information system.

1. Draw the efficiency and the power factor as functions of the electric power ($I = I_0 \dots 1,2 I_N$) of the induction generator connected to an infinite bus. Comment!
2. Draw the torque, current, and power factor curves of the induction motor as function of the speed. Compare with the theoretical curves.
3. Draw the no-load voltage of the independent generator as a function of the speed (with a few capacitors). Your notes on the excitation frequency?
4. Draw the dependence of the efficiency, voltage, current, and frequency of the independent generator running at constant speed on the load ($\cos\varphi = 1$). Your comments!
5. How do the stator voltage, current and flux vectors differ from each other in grid and frequency converter operation?

Facilitating Exercises**Exe. 1: Capacitor-excited induction machine as a generator**

The no-load curve $U_o = f(I_m)$ of a four-pole, star-connected squirrel-cage motor with $U_N = 380$ V, $P_N = 2.2$ kW, $f = 50$ Hz, is as follows:

U_o (V)	150	200	250	300	350	400
I_m (A)	0.75	1.0	1.35	1.75	2.3	3.15

The excitation current of the machine was supplied from delta-connected capacitors connected in parallel with the machine as shown in the figure 1.

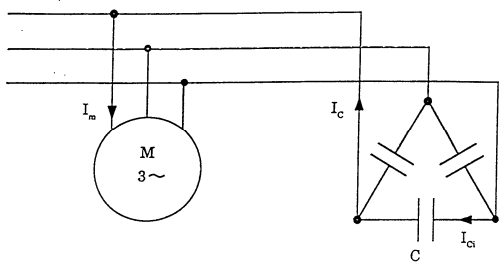


Figure 1: connection for the mesurement of the no-load curve of the independent induction generator.

Derive the no-load voltage of the machine as a function of the capacitance C , i.e., $U_o = f(C)$ at a speed of $n = 1500$ rpm? What is the minimum capacitance need for self-excitation of the machine?

Solution

The capacitors must be chosen so that they can supply the excitation current I_m :

$$I_m = \sqrt{3} I_{Cp}$$

$$I_{Cp} = U_o / X_c = \omega C U_o$$

$$\text{where } \omega = 2\pi f = 2\pi n p \quad (n \text{ in } s^{-1})$$

At $n = 25$ s⁻¹ (1500 rpm) and with a pole-pair number $p=2$, the electric frequency is $f = 50$ Hz.

The operation point of the machine at no-load settles at the intersection of the no-load curve $U_o = f(I_m)$ and the capacitor load-line $I_m = 2\pi f C \sqrt{3} U_o$.

Hence,
$$C = \frac{1}{\sqrt{3}} \frac{I_m}{2\pi f U_o}$$

The no-load voltage as a function of the capacitance is then calculated at each point of the machine no-load curve:

U_o (V)	150	200	250	300	350	400
C (μ F)	9.2	9.2	9.9	10.7	12.1	14.4

The smallest possible capacitance C_{krit} is obtained when the slope of the capacitor load-line is equal to the no-load curve's slope at the origin. In this case $C_{krit} = 9.2 \mu$ F.

If the machine is not running at synchronous speed, the voltage curve is scaled proportionally to the speed as illustrated in figure 2.

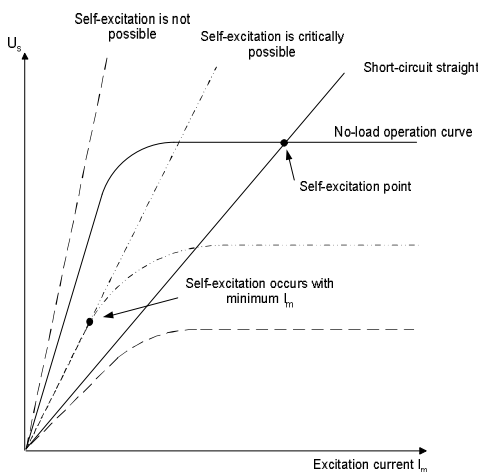


Figure 2. illustration of the scaling of the no-load curve of the generator at different speeds.

Exe. 2: Reactive-power compensation and self-excitation

The ratings of a four-pole, star-connected squirrel-cage motor are as follows:

$P_N = 11 \text{ kW}$, $U_N = 380 \text{ V}$, $f_N = 50 \text{ Hz}$, $\cos\phi = 0.86$ and $\eta = 0.88$.

The no-load curve is:

U_o (V)	150	200	250	300	380
I_m (A)	2.9	3.8	5.2	6.7	10.5

The reactive power of the motor is to be compensated with star-connected capacitors in parallel with the machine.

- a. How large the capacitors should be, and what is their reactive power?
- b. What is the minimum speed to achieve self-excitation of the machine?
- c. What is the minimum reactive power produced by the capacitors to achieve self-excitation of the machine

Solution

a. The nominal reactive power Q_N is obtained as follows:

$$Q_N = S_N \sin j_N$$

$$S_N = \frac{P_N}{\cos j_N}$$

$$S_N = \frac{11 \text{ kW}}{0,88 \times 0,86} = 14,53 \text{ kVA}$$

$$\sin j_N = 0,51$$

$$Q_N = 7,41 \text{ kVAr}$$

The capacitance required to produce this amount of reactive power is derived as:

$$I_C = \frac{U_N}{\sqrt{3}} \omega C$$

$$Q_N = Q_C = \sqrt{3} U_N I_C = U_N^2 \omega C$$

$$C = \frac{Q_N}{U_N^2 \omega} = 163,3 \text{ mF}$$

b. Self-excitation is possible when the capacitive reactance $X_C = 1/\omega C$ is smaller than the no-load curve's slope at the origin. In other words, the condition

$$X_C < \frac{\partial U_0}{\partial \omega} \frac{1}{\omega} \text{ must be met.}$$

For the critical frequency $f = n/p$ we get, assuming that the voltage is directly proportional to the speed of the machine:

$$\frac{1}{2p f C} \leq \frac{U_0 f}{\sqrt{3} I_m f_N}$$

$$f \geq \sqrt{\frac{f_N \sqrt{3} I_m}{2p U_0 C}} = \dots = 40,8 \text{ Hz}$$

Self-excitation is therefore possible only at speeds higher than $n = n_N f/f_N$, i.e. higher than

$$1500 \times 40,8/50 = 1224 \text{ rpm.}$$

c. The lowest self-exciting capacitance of a squirrel-cage machine is obtained at the highest speed used, $n = n_N = 1500 \text{ rpm}$.

The initial slope of the no-load curve yields the magnitude of the capacitance required for self-excitation of the induction machine:

$$X_C \leq \frac{U_0}{\sqrt{3} I_m} = \frac{150 \text{ V}}{\sqrt{3} \times 2,9 \text{ A}} = 29,9 \text{ W}$$

$$\text{at } f = np = 50 \text{ Hz}$$

$$\frac{1}{\omega C} \leq 29,9 \text{ W}, \quad C \geq 106,5 \mu\text{F}$$