Module 3 : Frequency Control in a Power System

Lecture 12 : Load Characteristics

Objectives

In this lecture you will learn the following

- Load - Frequency characteristic of typical loads.
- An example of the characteristics of an induction motor driven fan type load.

Load Frequency Characteristicsa

Normally, loads are a function of frequency. For example, a fan driven by an induction machine slows down and consumes lesser power if frequency is reduced. In the previous lecture we saw that a system will settle to a frequency at which load(+losses) and generation is balanced. Therefore it is instructive to examine the load behavior as a function of frequency.

For simplicity, let's assume voltage and frequency changes are small. In such a case, load can be represented (in steady state) as follows:

$$P_L = P_{L0}\left(1 + k_{pv}\frac{V - V_0}{V_0}\right)\left(1 + k_{pf}\frac{f - f_0}{f_0}\right)$$

$$Q_L = Q_{L0}\left(1 + k_{qv}\frac{V - V_0}{V_0}\right)\left(1 + k_{qf}\frac{f - f_0}{f_0}\right)$$

where P_{L0}, Q_{L0} are the real and reactive power at nominal voltage V_0 and frequency f_0.

Load Frequency Characteristics (Con td..)

Typical values for various loads are given below:

Component	Power factor	k_{pv}	k_{qv}	k_{pf}	k_{qf}
Refrigerator	0.80	0.77	2.5	0.53	-1.5
Incandescent lights	1.00	1.55	0.0	0.00	0.0
Fluorescent lights	0.90	0.96	7.4	1.00	-2.8

Industrial motors	0.88	0.07	0.5	2.50	1.2
Fan motors	0.87	0.08	1.6	2.90	1.7
Agricultural pumps	0.85	1.40	1.4	5.00	4.0
Arc furnace	0.70	2.30	1.6	-1.00	-1.0
Transformer (unloaded)	0.64	3.40	11.5	0.00	-11.8

We now consider an example to show how the parameters of an induction motor driven fan load can be obtained.

Induction machine Load

Consider an induction motor driving a fan type load.

The load torque for a fan is a function of speed ω_r.

Let us assume that the per-unit torque of the fan (on machine VA base) is given by :

$$T_L = 0.9\left(\frac{\omega_r}{\omega_{so}}\right)^2$$

where ω_{so} is the synchronous speed at nominal frequency (50 Hz).

The motor torque in per-unit as a function of slip is

$$T_m = \frac{V_e^2 \frac{R_r}{s}}{\left(R_e + \frac{R_r}{s}\right)^2 + (X_e + X_r)^2}$$

where

$$s = \frac{\omega_s - \omega_r}{\omega_s}$$

where, ω_s is the synchronous speed at the supply frequency.

R_r is the rotor resistance in p.u.

Induction machine Load

$$V_e = \frac{jX_m}{R_s + jX_s + jX_m} V$$
$$R_e + jX_e = \frac{jX_m(R_s + jX_s)}{R_s + jX_s + jX_m}$$

X_s, X_r and X_m are the stator leakage, rotor leakage and magnetising reactances in p.u. respectively at the supply frequency. Thus,

$$X_s = X_{so}\frac{\omega_s}{\omega_{so}},$$
$$X_r = X_{ro}\frac{\omega_s}{\omega_{so}},$$

$$X_m = X_{mo}\frac{\omega_s}{\omega_{so}}$$

X_{so}, X_{ro} and X_{mo} are the stator leakage, rotor leakage and magnetising reactances in p.u. respectively at the nominal frequency.
V is the supply voltage magnitude.

Induction machine Load

The operating speed is obtained from the equation

$$T_m(\omega_r) = T_L\ (\omega_r)$$

If the parameters of the induction motor (in p.u. on machine VA base) are :

$$X_{so} = 0.065 \qquad R_s = 0.078$$
$$X_{ro} = 0.049 \qquad R_r = 0.044$$
$$X_{mo} = 2.67$$

Let $V = 1.0$ p.u.
Compute the change in power drawn by the induction machine for 1 Hz decrease in frequency

from the nominal (50 Hz).

Solution :

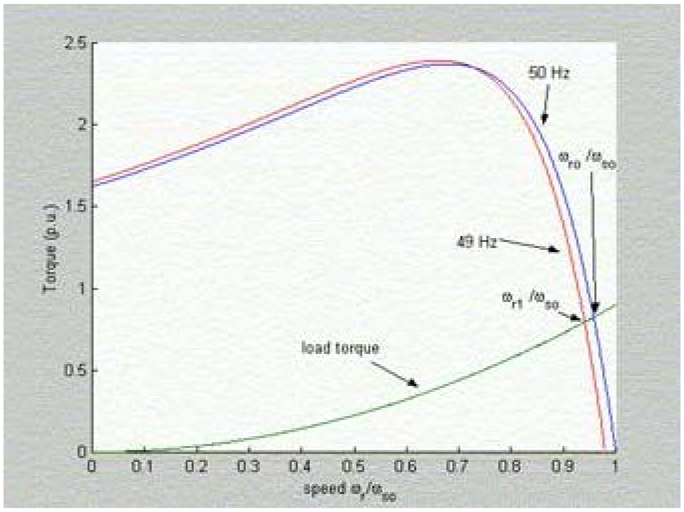
Using the formulae given above we can plot T_m and T_L vs $\frac{\omega_r}{\omega_{so}}$ as shown below

Clearly there is a decrease in the operating speed ($\frac{\omega_{ro}}{\omega_{so}} = 0.9579$ and $\frac{\omega_{r1}}{\omega_{so}} = 0.9405$).

and torque as the frequency decreases.

The percentage change in power (drawn from source) for percent change in frequency is given by :

$$k_{pf} = \frac{\Delta P}{P_o}\frac{\omega_{so}}{\Delta\omega_s} = \frac{0.8558 - 0.8232}{0.8558} * \frac{50}{1} = 1.90$$



Recap

In this lecture you have learnt the following

- Motor loads like fans, agricultural pumps usually have a significant frequency dependence.

Congratulations, you have finished Lecture 12. To view the next lecture select it from the left hand side menu of the page.