Understanding the operational impedances

Important questions

- Why we need to introduce them?
- How their values are determined?

The main purpose is

To have an easier way to solve <u>analytically</u> the d, q-axes voltage equations (involving the flux linkage equations).

The convenience offered by the 'easier way' is obtained by neglecting the rotor currents.

Example – q-axis equations

Original equations (lecture 5, slide 12, for a generator)

$$u_q = -Ri_q + p\lambda_q + \omega_r \lambda_d \qquad \lambda_q = -L_{ls} i_q + L_{mq}\left(-i_q + i'_{kq}\right)$$

$$u_d = -Ri_d + p\lambda_d - \omega_r \lambda_q \qquad \lambda_d = -L_{ls} i_d + L_{md}\left(-i_d + i'_{fd} + i'_{kd}\right)$$

It will be easier to solve the equations if e.g. λ_q is only related to i_q only.

This requires to get rid of i'_{kq} … by using the rotor side voltage equation:

$$0 = u'_{kq} = R'_{kq} i'_{kq} + p\lambda'_{kq} \qquad \lambda'_{kq} = L'_{lkq} i'_{kq} + L_{mq}\left(-i_q + i'_{kq}\right)$$

What we do is to introduce an equivalent circuit

$$0 = u'_{kq} = R'_{kq} i'_{kq} + p\lambda'_{kq}$$

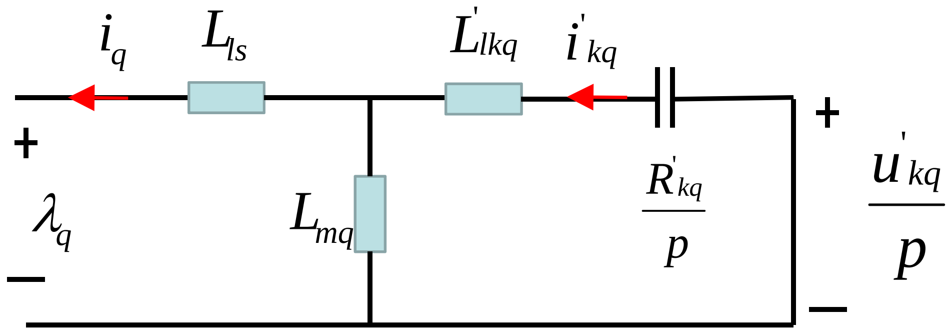
$$\Downarrow$$

$$0 = \frac{u'_{kq}}{p} = \frac{R'_{kq}}{p} i'_{kq} + \lambda'_{kq}$$

$$\lambda_q = -L_{ls} i_q + L_{mq}\left(-i_q + i'_{kq}\right)$$

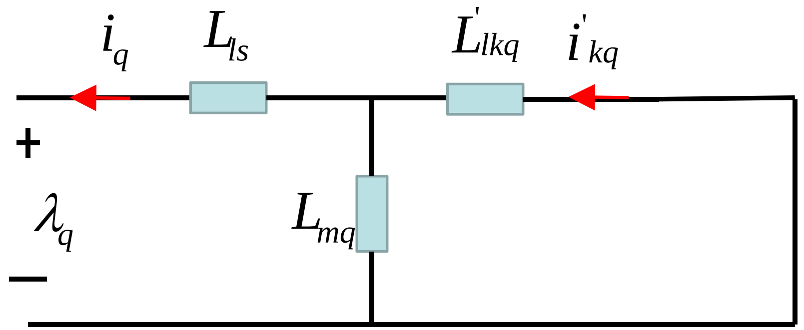
$$\lambda'_{kq} = L'_{lkq} i'_{kq} + L_{mq}\left(-i_q + i'_{kq}\right)$$

Imaging the flux linkage is ‘voltage’ and inductance is the ‘resistance’, the equivalent electrical circuit can be obtained as



Therefore we find the equivalent inductance

Under the assumption that the q-axis damping winding resistance is neglected, we have



The equivalent inductance of this circuit becomes

$$L_{ls} + \frac{L'_{lkq} L_{mq}}{L'_{lkq} + L_{mq}} \quad \Longrightarrow \quad X_{ls} + \frac{X'_{lkq} X_{mq}}{X'_{lkq} + X_{mq}}$$

Multiplied by ω_e, we obtain

Known as the transient reactance.

The relation between λ_q and i_q is now simply determined by this inductance.

Similar idea for the sub-transient reactance

This corresponds to the situation that if you add one more damping winding on the q-axis and the equivalent input reactance will be the sub-transient reactance.

Note – the damping winding resistances are always neglected.

Similar idea may be applied for the d-axis.