即将直播授课

- 下载腾讯课堂学生端APP：
  https://ke.qq.ocm/s
- 扫码进课
- 也可以看回放
- 进一次以后，下次再进课堂不需要再扫码：
  我的—最近看过—刘崇茹的课堂
- 请将昵称改为：学号姓名

派克变换的应用实例之二——发电机等值电路

电压方程

$$u_d = -r_a i_d + \dot{\psi}_d - \omega\psi_q$$

$$u_q = -r_a i_q + \dot{\psi}_q + \omega\psi_d$$

假设：

1、忽略定子回路的电磁暂态过程；

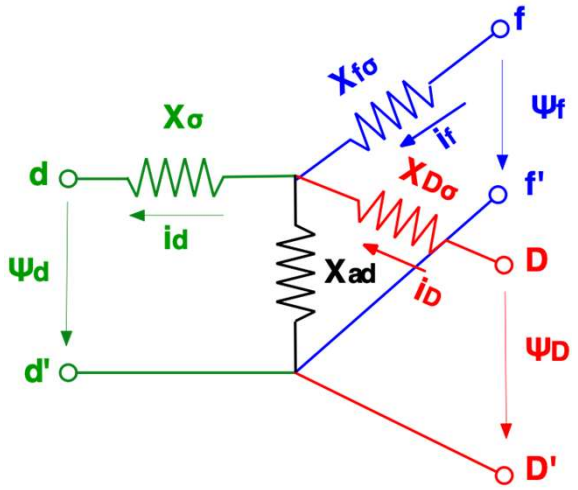
2、电磁暂态过程中，转速维持同步速；

3、忽略定子电阻。

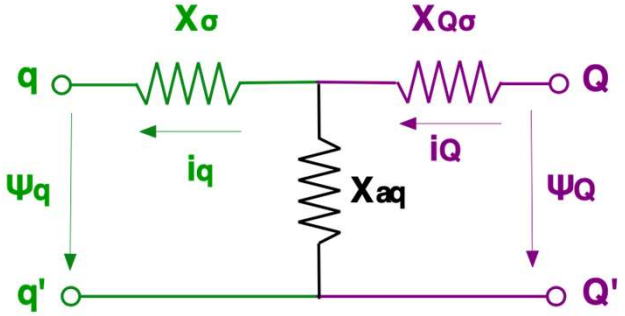
$$u_d = -\psi_q \qquad u_q = \psi_d$$

将磁链和电流的关系带入电压与磁链的关系即可得到发电机在稳态、暂态和次暂态情况下的戴维南等值电路及其参数。

d轴磁链和电流的关系

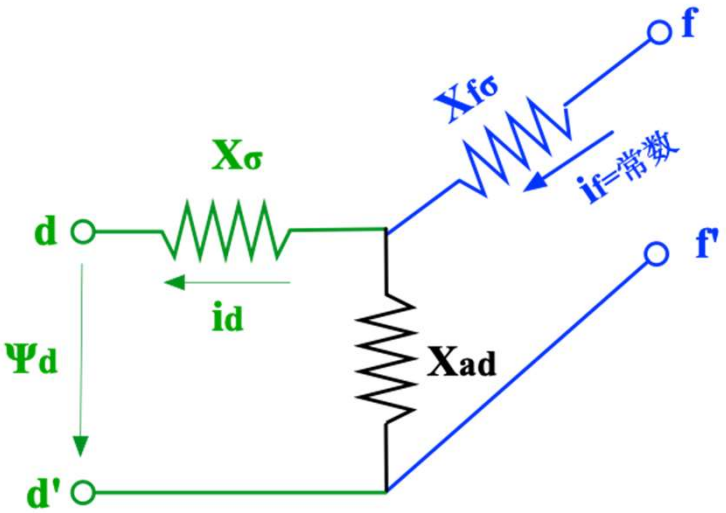


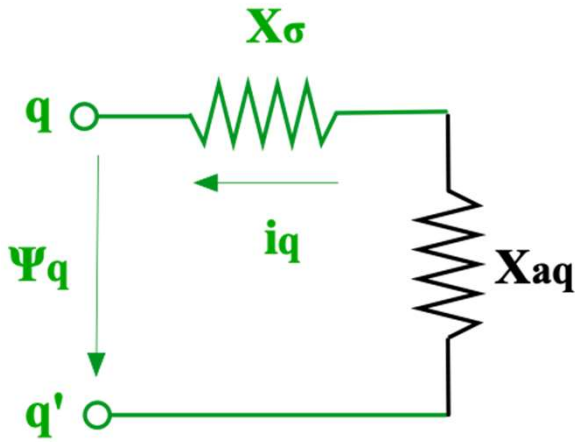
q轴磁链和电流的关系

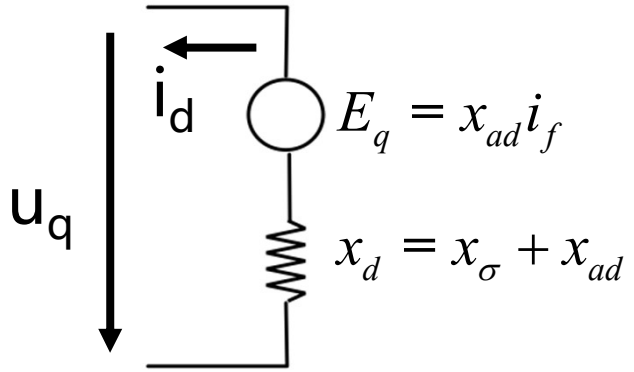


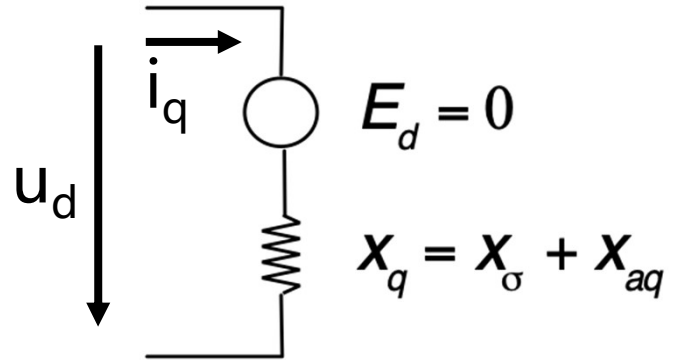
派克变换的应用实例之二——发电机等值电路

- 稳态等值电路 ⟹ $i_D=0$，$i_Q=0$，$i_f=$常数



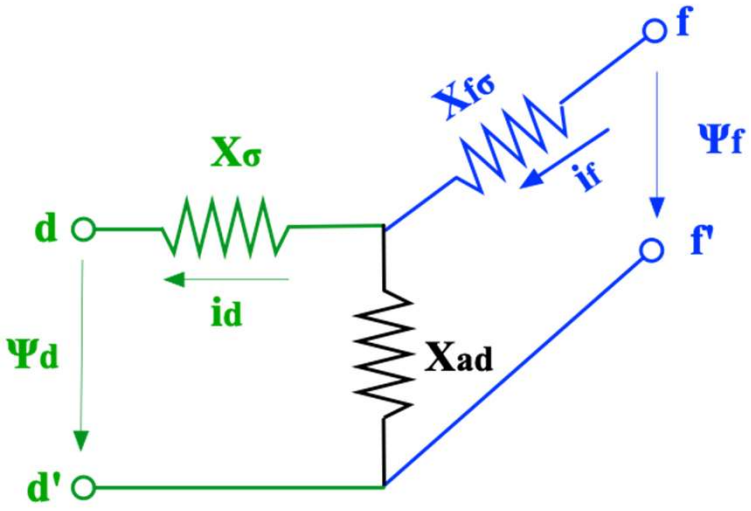


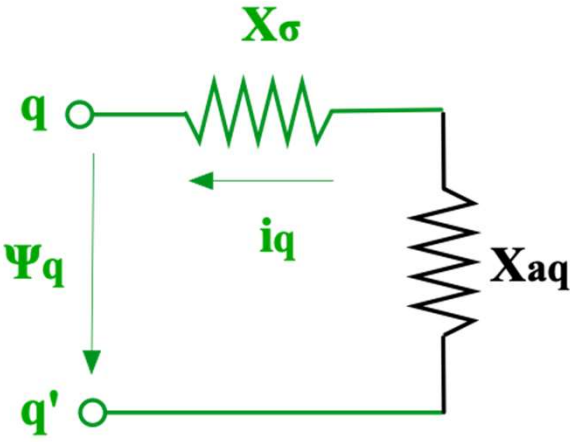


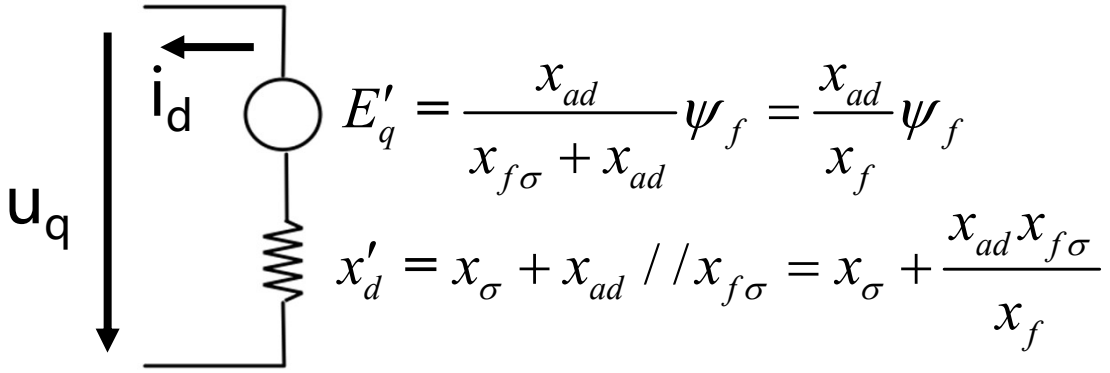


派克变换的应用实例之二——发电机等值电路

- 暂态等值电路 ⇒ $i_D=0$，$i_Q=0$

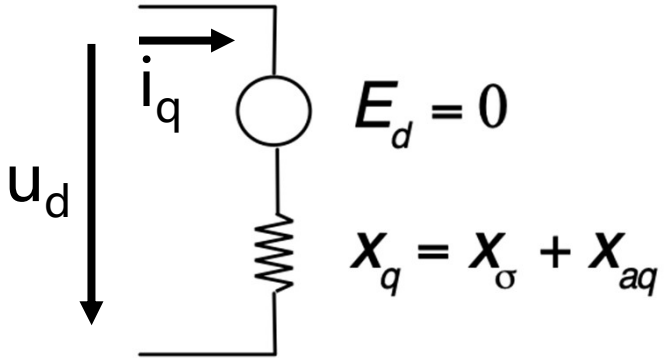






$$E'_q = \frac{x_{ad}}{x_{f\sigma}+x_{ad}}\psi_f = \frac{x_{ad}}{x_f}\psi_f$$

$$x'_d = x_\sigma + x_{ad}//x_{f\sigma} = x_\sigma + \frac{x_{ad}x_{f\sigma}}{x_f}$$



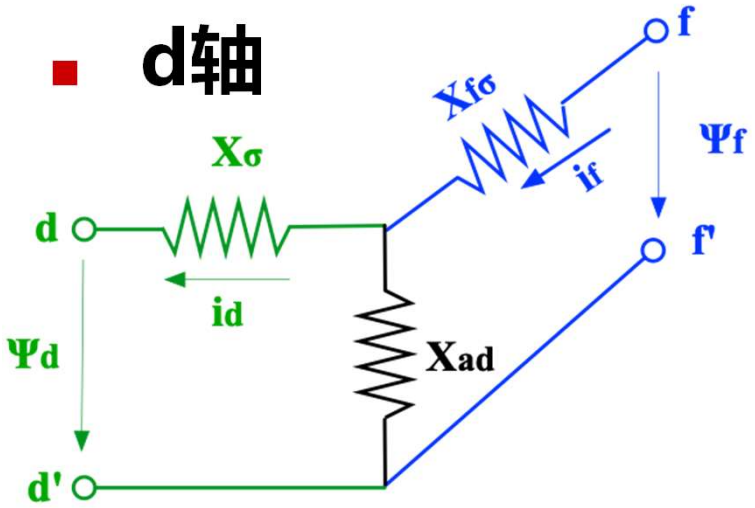
$$E_d = 0$$

$$X_q = X_\sigma + X_{aq}$$

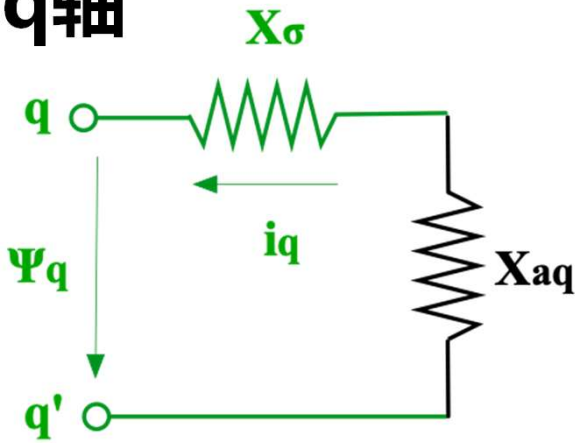
派克变换的应用实例之二——发电机等值电路

- 暂态衰减时间常数 → $i_D=0$，$i_Q=0$

- d轴



- q轴



- 衰减时间常数（X/R）
  - Td'由f-f'等值参数确定
  - Ta由定子绕组等值参数确定

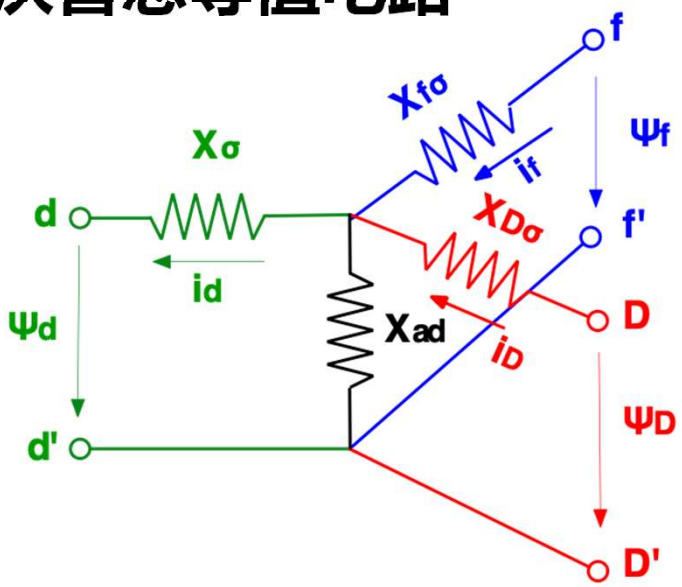
$$T_d' = \frac{x_{f-f'}}{R_f} \qquad T_a = \frac{x_{eq}}{R_a}$$

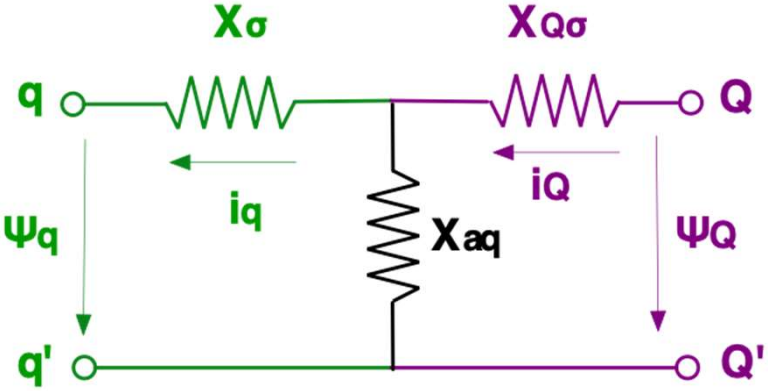
$$T_d' = \left(x_{f\sigma} + \frac{x_{ad}x_\sigma}{x_{ad}+x_\sigma} \right) \Big/ R_f$$

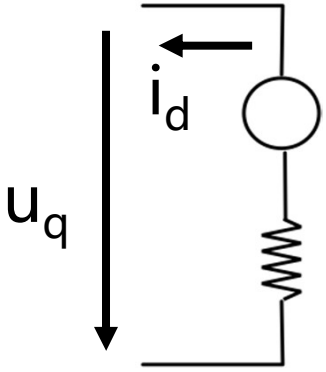
$$T_a = \left(\frac{2x_d'x_q}{x_d'+x_q} \right) \Big/ R$$

派克变换的应用实例之二——发电机等值电路

- 次暂态等值电路



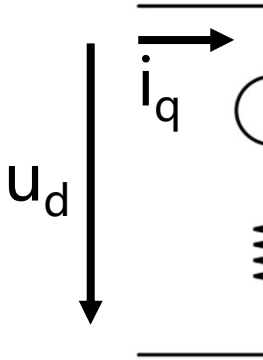




$$E_q'' = \frac{x_{ad}//x_{D\sigma}}{x_{f\sigma}+x_{ad}//x_{D\sigma}}\psi_f + \frac{x_{ad}//x_{f\sigma}}{x_{D\sigma}+x_{ad}//x_{f\sigma}}\psi_D$$

$$x_d'' = x_\sigma + x_{ad}//x_{f\sigma}//x_{D\sigma}$$

$$= x_\sigma + \frac{x_{ad}x_{f\sigma}x_{D\sigma}}{x_{ad}x_{f\sigma}+x_{ad}x_{D\sigma}+x_{f\sigma}x_{D\sigma}}$$



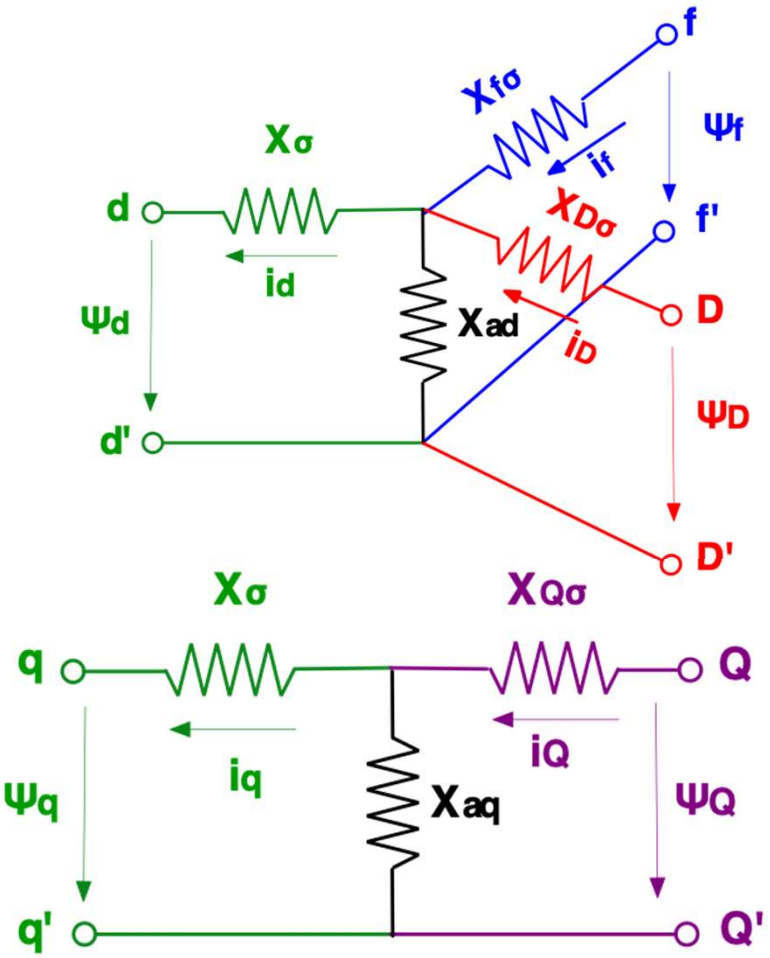
$$E_d'' = \frac{x_{aq}}{x_Q}\psi_Q$$

$$x_q'' = x_\sigma + x_{aq}//x_{Q\sigma}$$

$$= x_\sigma + \frac{x_{aq}x_{Q\sigma}}{x_Q}$$

派克变换的应用实例之二——发电机等值电路

- 次暂态衰减时间常数



- 衰减时间常数（X/R）
  - Td”由D-D'等值参数确定
  - Tq”由Q-Q'等值参数确定
  - Ta由定子绕组等值参数确定

$$T_d''=\frac{x_{D-D'}}{R_D}\qquad T_q''=\frac{x_{Q-Q'}}{R_Q}\qquad T_a=\frac{x_{eq}}{R_a}$$

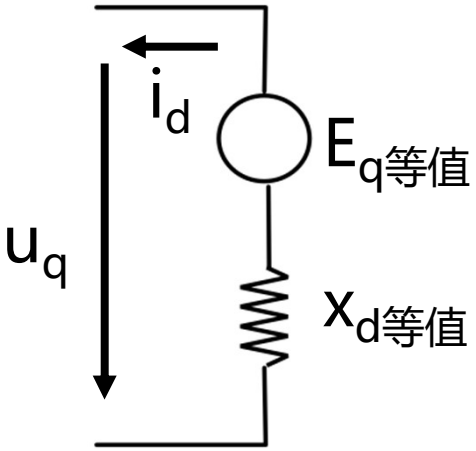
$$T_d''=\left(x_{D\sigma}+\frac{x_{ad}x_\sigma x_{f\sigma}}{x_{ad}x_\sigma+x_{ad}x_{f\sigma}+x_\sigma x_{f\sigma}}\right)\Big/R_D$$

$$T_q''=\left(x_{Q\sigma}+\frac{x_{aq}x_\sigma}{x_{aq}+x_\sigma}\right)\Big/R_Q$$

$$T_a=\left(\frac{2x_d''x_q''}{x_d''+x_q''}\right)\Big/R$$

派克变换的应用实例之三——发电机短路电流计算

- **发电机等值电路**



稳态

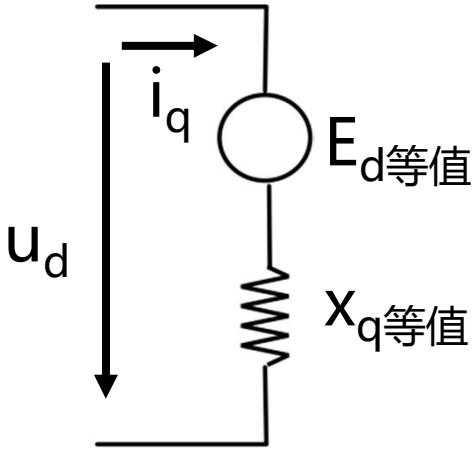
$$E_q = x_{ad} i_f \qquad E_d = 0$$

$$x_d = x_\sigma + x_{ad} \qquad X_q = X_\sigma + X_{aq}$$

暂态

$$E'_q = \frac{x_{ad}}{x_f}\psi_f \qquad E_d = 0$$

$$x'_d = x_\sigma + x_{ad} // x_{f\sigma} \qquad X_q = X_\sigma + X_{aq}$$



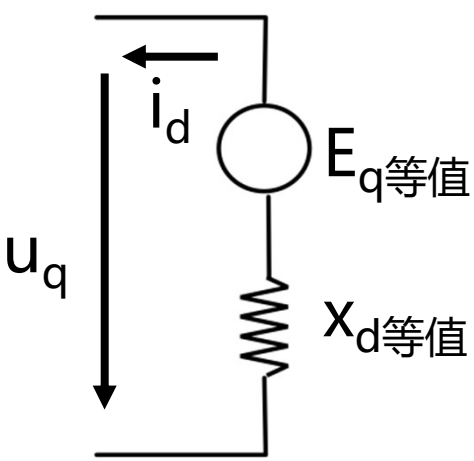
次暂态

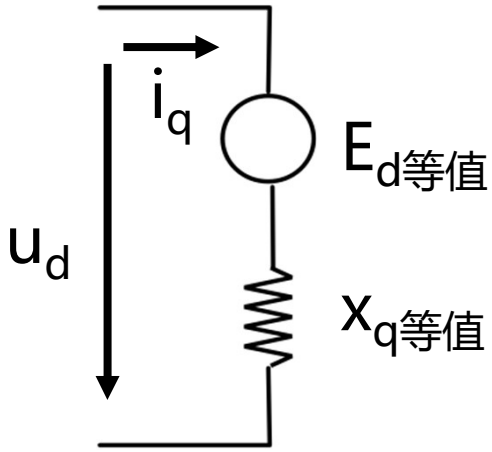
$$E''_q = \frac{x_{ad} // x_{D\sigma}}{x_{f\sigma} + x_{ad} // x_{D\sigma}}\psi_f + \frac{x_{ad} // x_{f\sigma}}{x_{D\sigma} + x_{ad} // x_{f\sigma}}\psi_D \qquad E''_d = \frac{x_{aq}}{x_Q}\psi_Q$$

$$x''_d = x_\sigma + x_{ad} // x_{f\sigma} // x_{D\sigma} \qquad x''_q = x_\sigma + x_{aq} // x_{Q\sigma}$$

派克变换的应用实例之三——发电机短路电流计算

- **发电机等值电路**





$$u_q = E_q^{eq} - i_d x_d^{eq}$$

$$u_d = E_d^{eq} + i_q x_q^{eq}$$

稳态

$$u_q = E_q - i_d x_d$$

$$u_d = E_d + i_q x_q = i_q x_q$$

暂态

$$u_q = E'_q - i_d x'_d$$

$$u_d = E_d + i_q x_q = i_q x_q$$

次暂态

$$u_q = E''_q - i_d x''_d$$

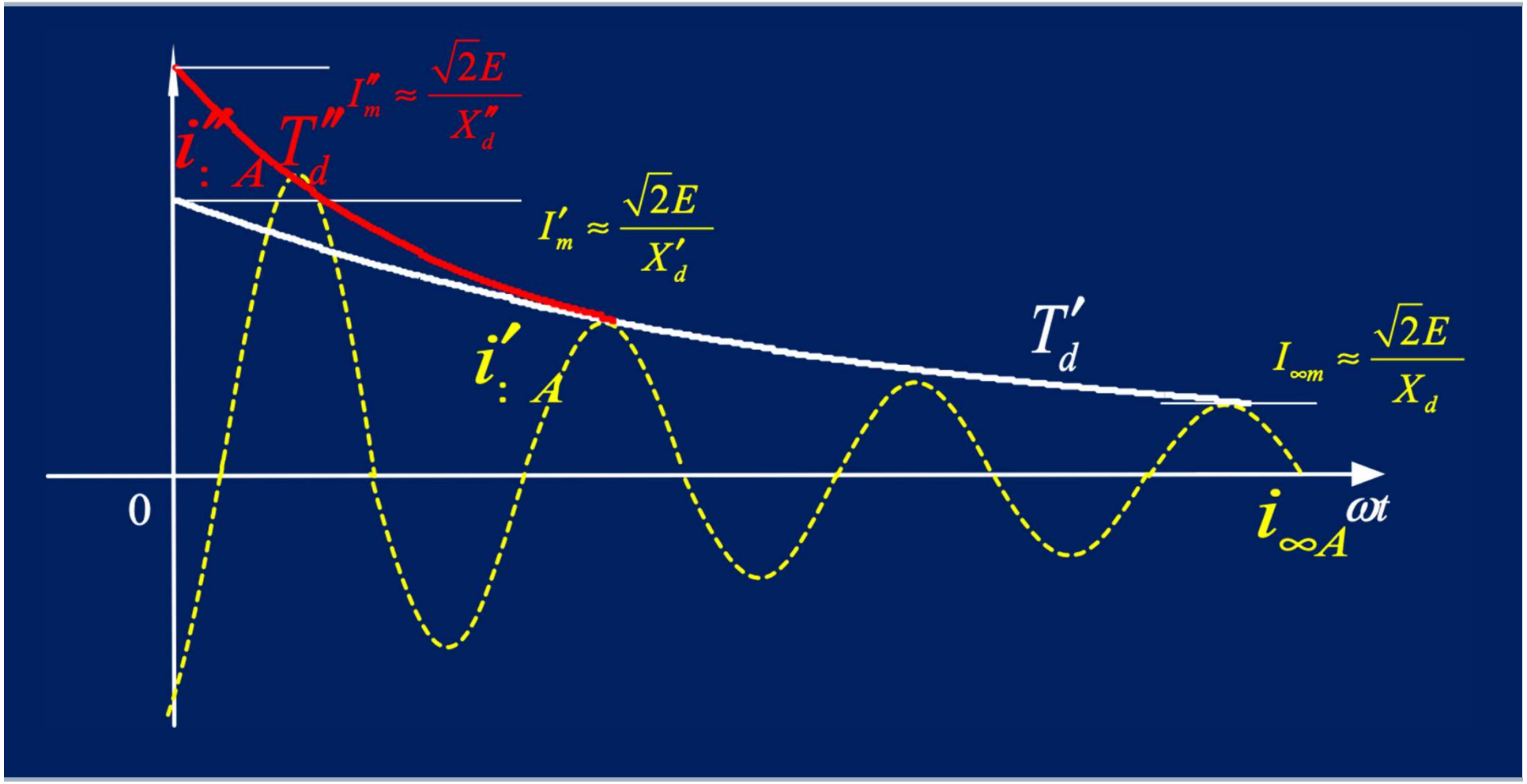
$$u_d = E''_d + i_q x''_q$$

空载情况下：各等值电势有什么关系？

派克变换的应用实例之三——发电机短路电流计算

- 空载情况下
  - d轴：$E_{q|0|}=E'_{q|0|}=E''_{q|0|}=u_{q|0|}$
  - q轴：$E_{d|0|}=E''_{d|0|}=u_{d|0|}=0$
- 空载短路电流初始值
  - 次暂态电流：D轴阻尼绕组电流没有衰减到零
    - 有效值：$I'' = I''_d = E''_{q|0|}/x''_d = E_{q|0|}/x''_d$
  - 暂态电流：励磁绕组的直流分量没有衰减结束
    - 有效值：$I' = I'_d = E'_{q|0|}/x'_d = E_{q|0|}/x'_d$
  - 稳态值：衰减过程结束后的稳态短路电流
    - 有效值：$I_\infty = I_{d\infty} = E_{q|0|}/x_d$

发电机短路电流



《电机学》第十七章内容

派克变换的应用实例之三——发电机短路电流计算

- **空载短路电流近似表达式**

衰减时间常数**T'd**

$$I'' = I''_{\mathrm{d}} = E_{\mathrm{q|0|}} \Big/ X''_{\mathrm{d}} \qquad I' = I'_{\mathrm{d}} = E_{\mathrm{q|0|}} \Big/ X'_{\mathrm{d}} \qquad I_{\infty} = I_{\mathrm{d}\infty} = E_{\mathrm{q|0|}} \Big/ X_{\mathrm{d}}$$

衰减时间常数**T"d**

$$I_m(t) = \left(\sqrt{2}I'' - \sqrt{2}I'\right)e^{-\frac{t}{T''_d}} + \left(\sqrt{2}I' - \sqrt{2}I_{\infty}\right)e^{-\frac{t}{T'_d}} + \sqrt{2}I_{\infty}$$

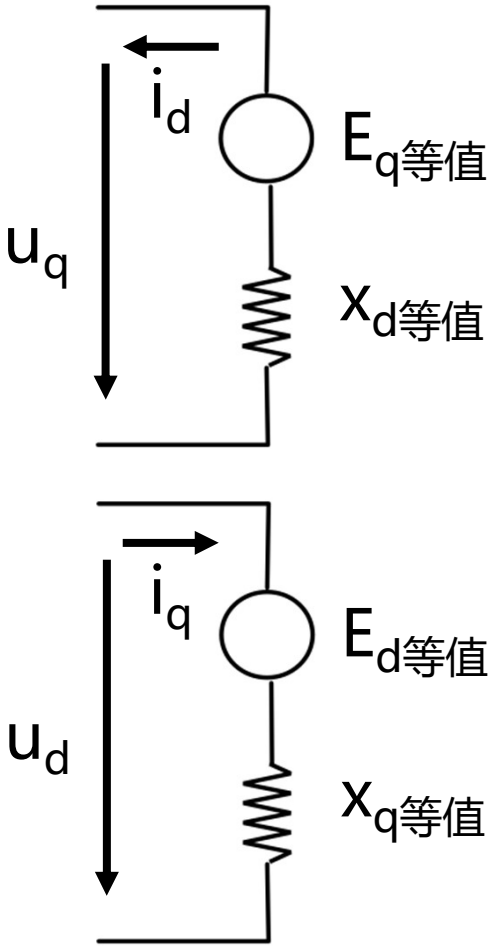
$$i_a = \sqrt{2}E_{q|0|}\left[\left(\frac{1}{x''_d} - \frac{1}{x'_d}\right)e^{-\frac{t}{T''_d}} + \left(\frac{1}{x'_d} - \frac{1}{x_d}\right)e^{-\frac{t}{T'_d}} + \frac{1}{x_d}\right]\cos(\theta_0 + \omega_0 t) - \frac{\sqrt{2}E_{q|0|}}{x''_d}\cos\theta_0 e^{-\frac{t}{T_a}}$$

$$i_b = \sqrt{2}E_{q|0|}\left[\left(\frac{1}{x''_d} - \frac{1}{x'_d}\right)e^{-\frac{t}{T''_d}} + \left(\frac{1}{x'_d} - \frac{1}{x_d}\right)e^{-\frac{t}{T'_d}} + \frac{1}{x_d}\right]\cos(\theta_0 + \omega_0 t - 120^\circ) - \frac{\sqrt{2}E_{q|0|}}{x''_d}\cos(\theta_0 - 120^\circ)e^{-\frac{t}{T_a}}$$

$$i_c = \sqrt{2}E_{q|0|}\left[\left(\frac{1}{x''_d} - \frac{1}{x'_d}\right)e^{-\frac{t}{T''_d}} + \left(\frac{1}{x'_d} - \frac{1}{x_d}\right)e^{-\frac{t}{T'_d}} + \frac{1}{x_d}\right]\cos(\theta_0 + \omega_0 t + 120^\circ) - \frac{\sqrt{2}E_{q|0|}}{x''_d}\cos(\theta_0 + 120^\circ)e^{-\frac{t}{T_a}}$$

派克变换的应用实例之三——发电机短路电流计算

- **负载情况下**



暂态电流初始值

$$\dot{I}'_d = \dot{E}'_{q|0|} / jx'_d$$

次暂态电流初始值

$$\dot{I}''_d = \dot{E}''_{q|0|} / jx''_d$$

$$\dot{I}''_q = \dot{E}''_{d|0|} / jx''_q$$

虚构次暂态电动势

$$\dot{E}''_{|0|} = \dot{U}_{|0|} + \mathrm{j}\dot{I}_{|0|} X''_{\mathrm{d}}$$

$$I'' = E''_{|0|} / X''_{\mathrm{d}}$$

(此定义与40页例1-3不一致)

空载

$$I' = I'_{\mathrm{d}} = E_{\mathrm{q}|0|} \Big/ X'_{\mathrm{d}}$$

$$I'' = I''_{\mathrm{d}} = E_{\mathrm{q}|0|} \Big/ X''_{\mathrm{d}}$$

负载

$$I' = E'_{\mathrm{q}|0|} \Big/ X'_{\mathrm{d}}$$

$$I'' = E''_{|0|} / X''_{\mathrm{d}}$$

提问：负载短路电流和空载短路电流谁大？

发电机机端发生三相短路，空载时和带负载时，短路电流哪个大?

A 空载短路电流大于负载短路电流

B 负载短路电流大于空载短路电流

C 不能确定

D 不知道