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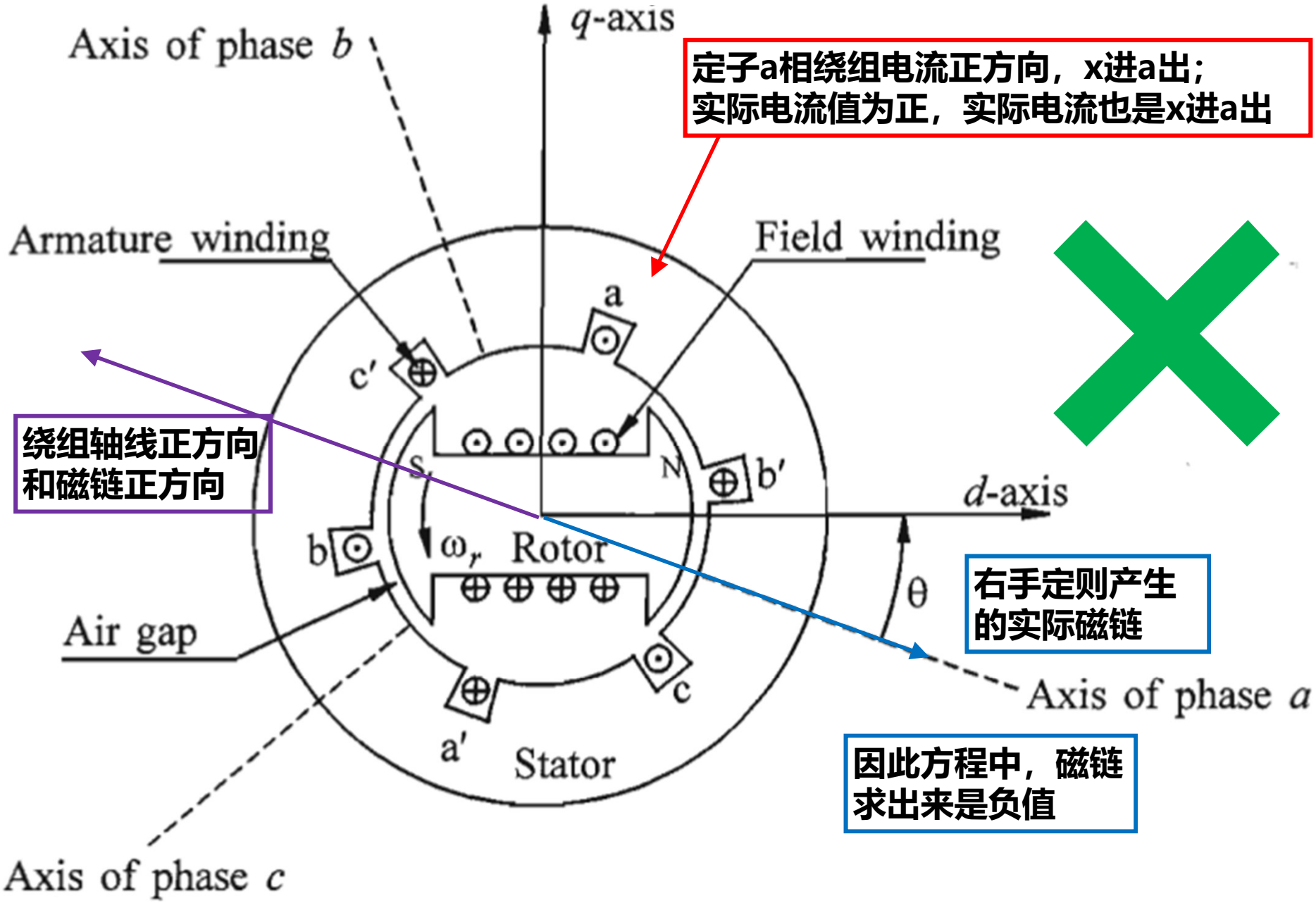
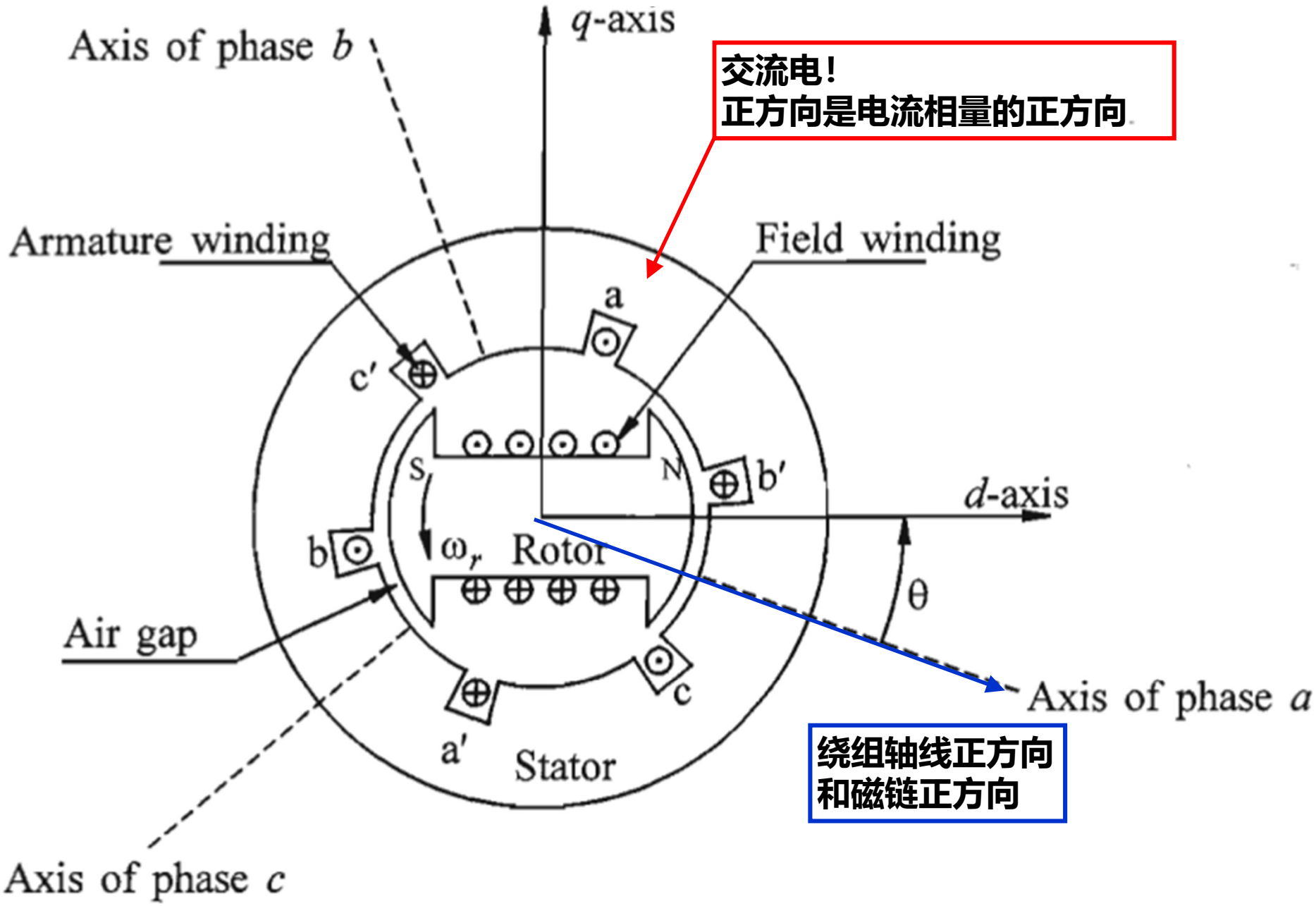
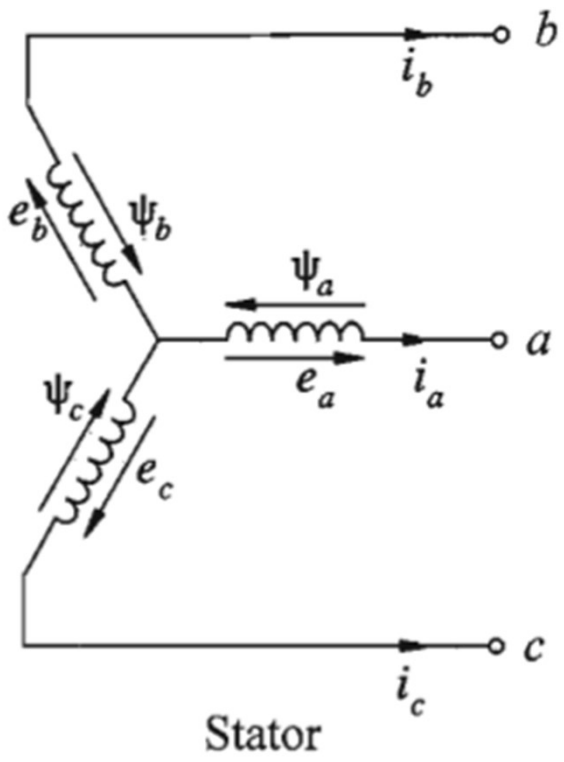

Axis of phase b
q-axis
定子a相绕组电流正方向，x进a出；
实际电流值为正，实际电流也是x进a出
Armature winding
Field winding
a
c′
绕组轴线正方向
和磁链正方向
S
N
b′
d-axis
b
ω_r
Rotor
θ
右手定则产生
的实际磁链
Air gap
c
Axis of phase a
a′
Stator
因此方程中，磁链
求出来是负值
Axis of phase c

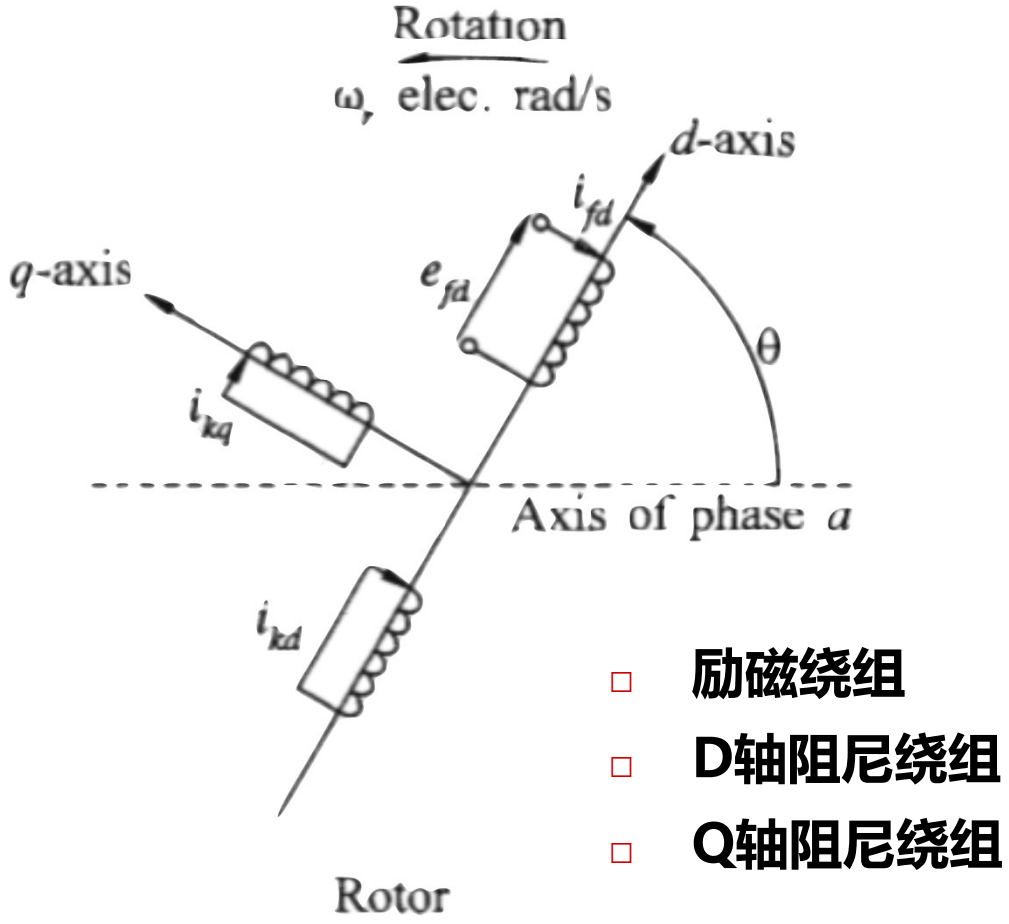

Axis of phase b
q-axis
交流电!
正方向是电流相量的正方向
Armature winding
Field winding
a
c′
b′
S
N
d-axis
b
ω_r
Rotor
θ
Air gap
c
Axis of phase a
a′
Stator
绕组轴线正方向
和磁链正方向
Axis of phase c

同步发电机的回路

- 发电机有六个回路
  - 定子绕组



  - 转子绕组

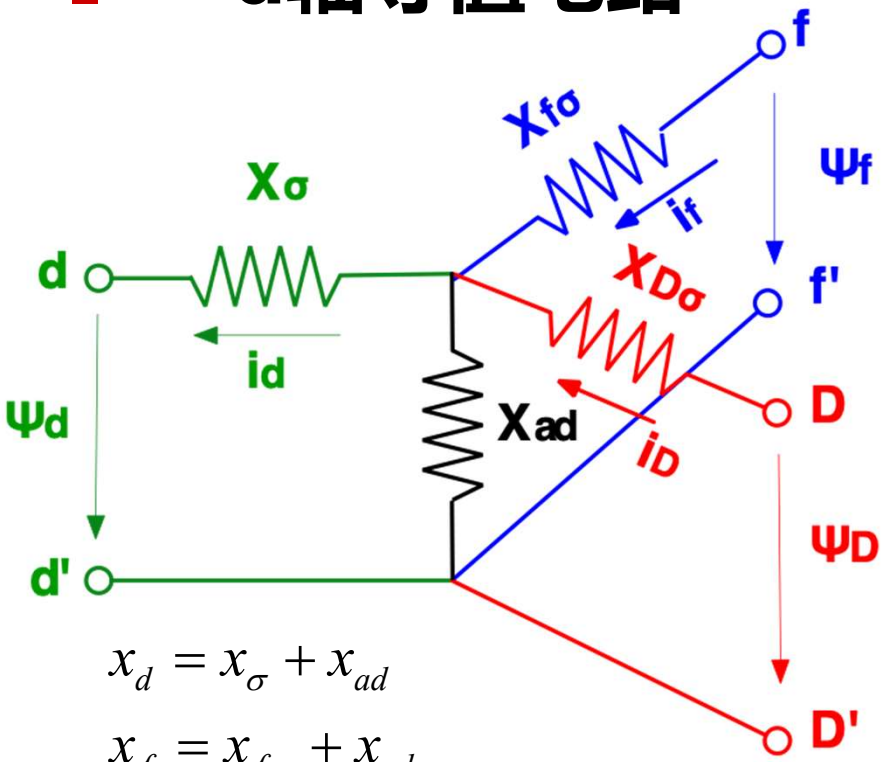


    - 励磁绕组
    - D轴阻尼绕组
    - Q轴阻尼绕组

派克变换的应用实例之二——发电机等值电路

- 磁链和电流的关系

- d轴等值电路

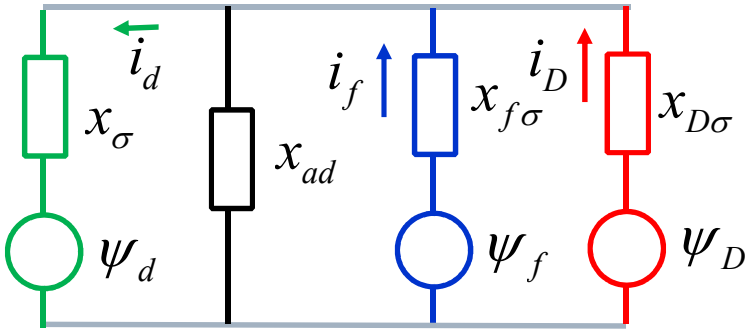


$$x_d = x_\sigma + x_{ad}$$

$$x_f = x_{f\sigma} + x_{ad}$$

$$x_D = x_{D\sigma} + x_{ad}$$

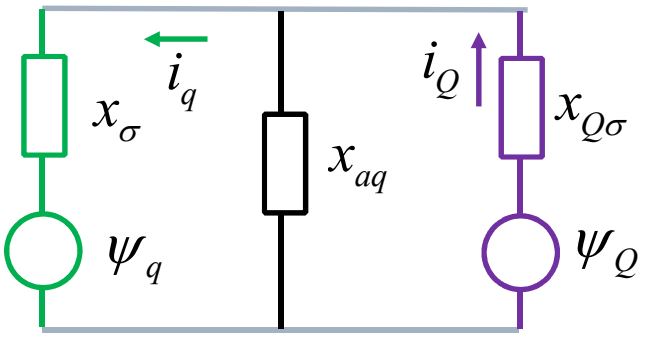
$$\begin{bmatrix} \psi_d \\ \psi_q \\ \psi_0 \\ \psi_f \\ \psi_D \\ \psi_Q \end{bmatrix} = \begin{bmatrix} x_d & 0 & 0 & x_{ad} & x_{ad} & 0 \\ 0 & x_q & 0 & 0 & 0 & x_{aq} \\ 0 & 0 & x_0 & 0 & 0 & 0 \\ x_{ad} & 0 & 0 & x_f & x_{ad} & 0 \\ x_{ad} & 0 & 0 & x_{ad} & x_D & 0 \\ 0 & x_{aq} & 0 & 0 & 0 & x_Q \end{bmatrix} \begin{bmatrix} -i_d \\ -i_q \\ -i_0 \\ i_f \\ i_D \\ i_Q \end{bmatrix}$$



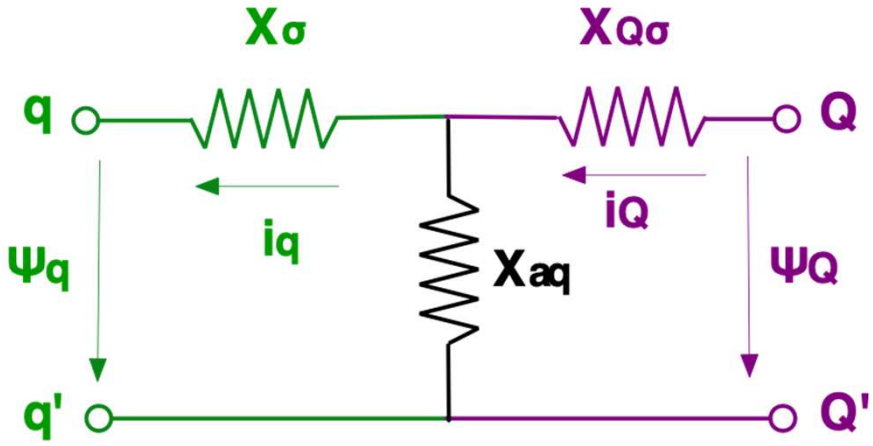
派克变换的应用实例之二——发电机等值电路

- 磁链和电流的关系

$$\begin{bmatrix}\psi_d\\ \psi_q\\ \psi_0\\ \psi_f\\ \psi_D\\ \psi_Q\end{bmatrix}=\begin{bmatrix}x_d & 0 & 0 & x_{ad} & x_{ad} & 0\\ 0 & x_q & 0 & 0 & 0 & x_{aq}\\ 0 & 0 & x_0 & 0 & 0 & 0\\ x_{ad} & 0 & 0 & x_f & x_{ad} & 0\\ x_{ad} & 0 & 0 & x_{ad} & x_D & 0\\ 0 & x_{aq} & 0 & 0 & 0 & x_Q\end{bmatrix}\begin{bmatrix}-i_d\\ -i_q\\ -i_0\\ i_f\\ i_D\\ i_Q\end{bmatrix}$$



- q轴等值电路

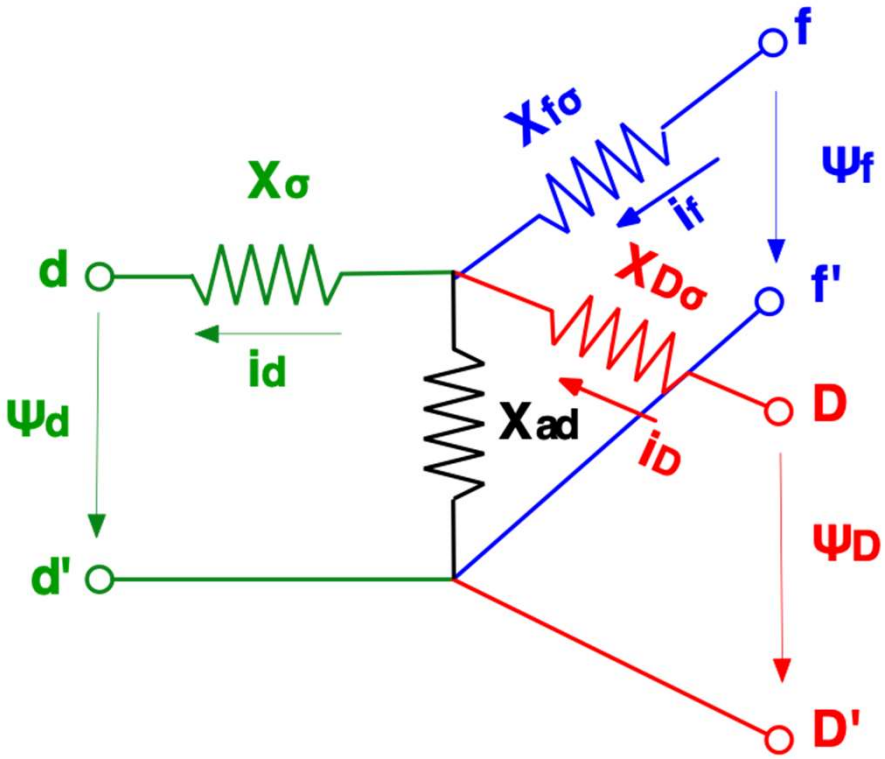


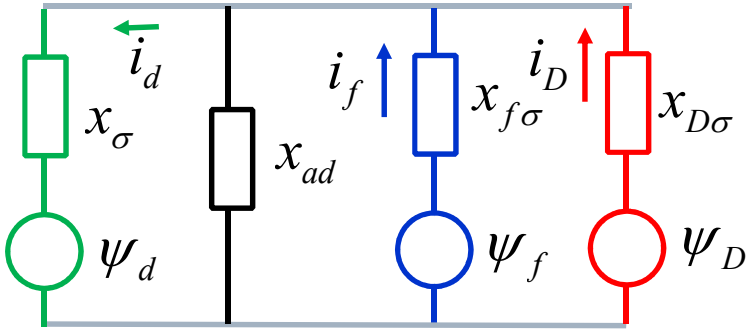
$$x_q = x_\sigma + x_{aq}$$

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

派克变换的应用实例之二——发电机等值电路

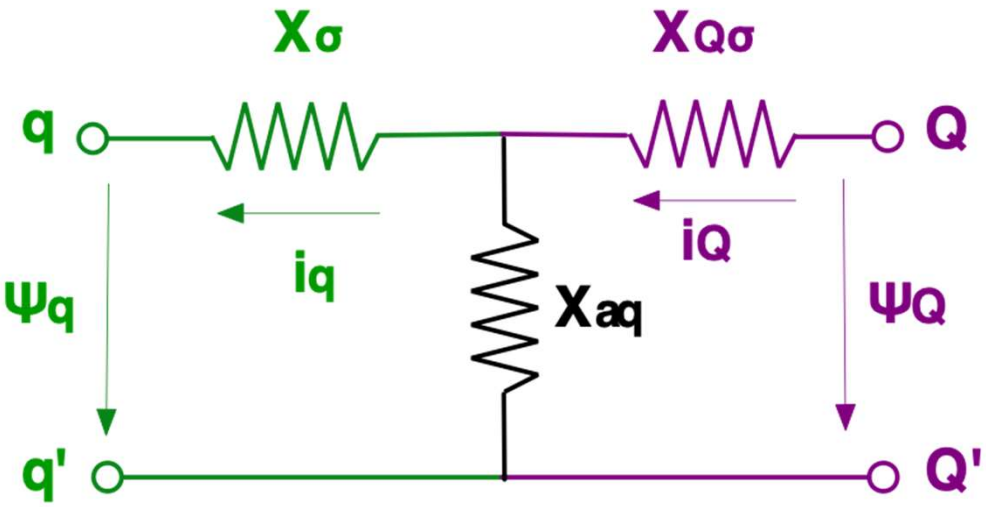
- 磁链和电流的关系
- d轴等值电路

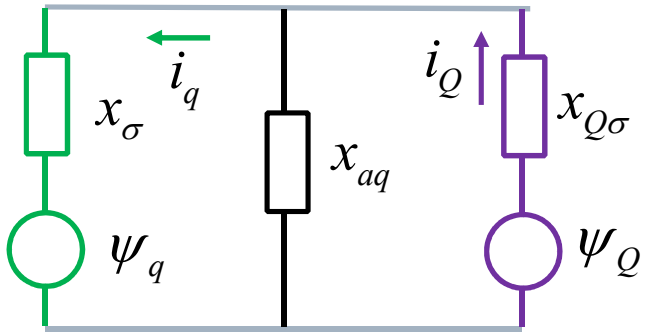




派克变换的应用实例之二——发电机等值电路

- 磁链和电流的关系
- q轴等值电路





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；

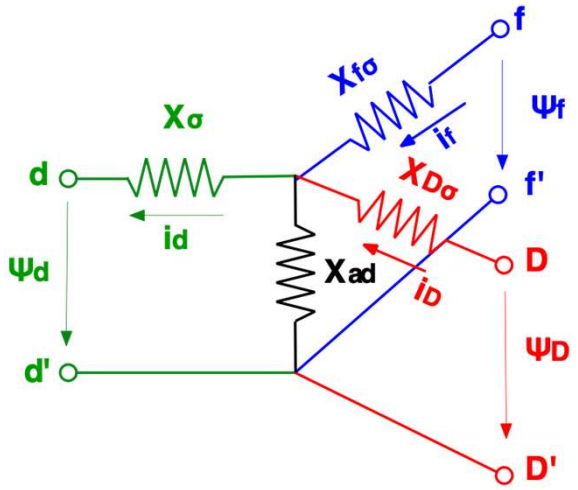
2、电磁暂态过程中，转速维持同步速；

3、忽略定子电阻。

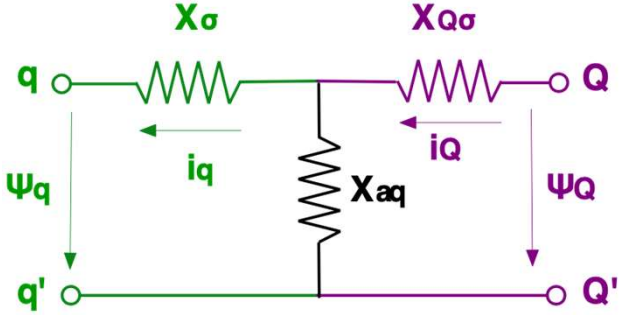
$$u_d = -\psi_q \qquad u_q = \psi_d$$

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

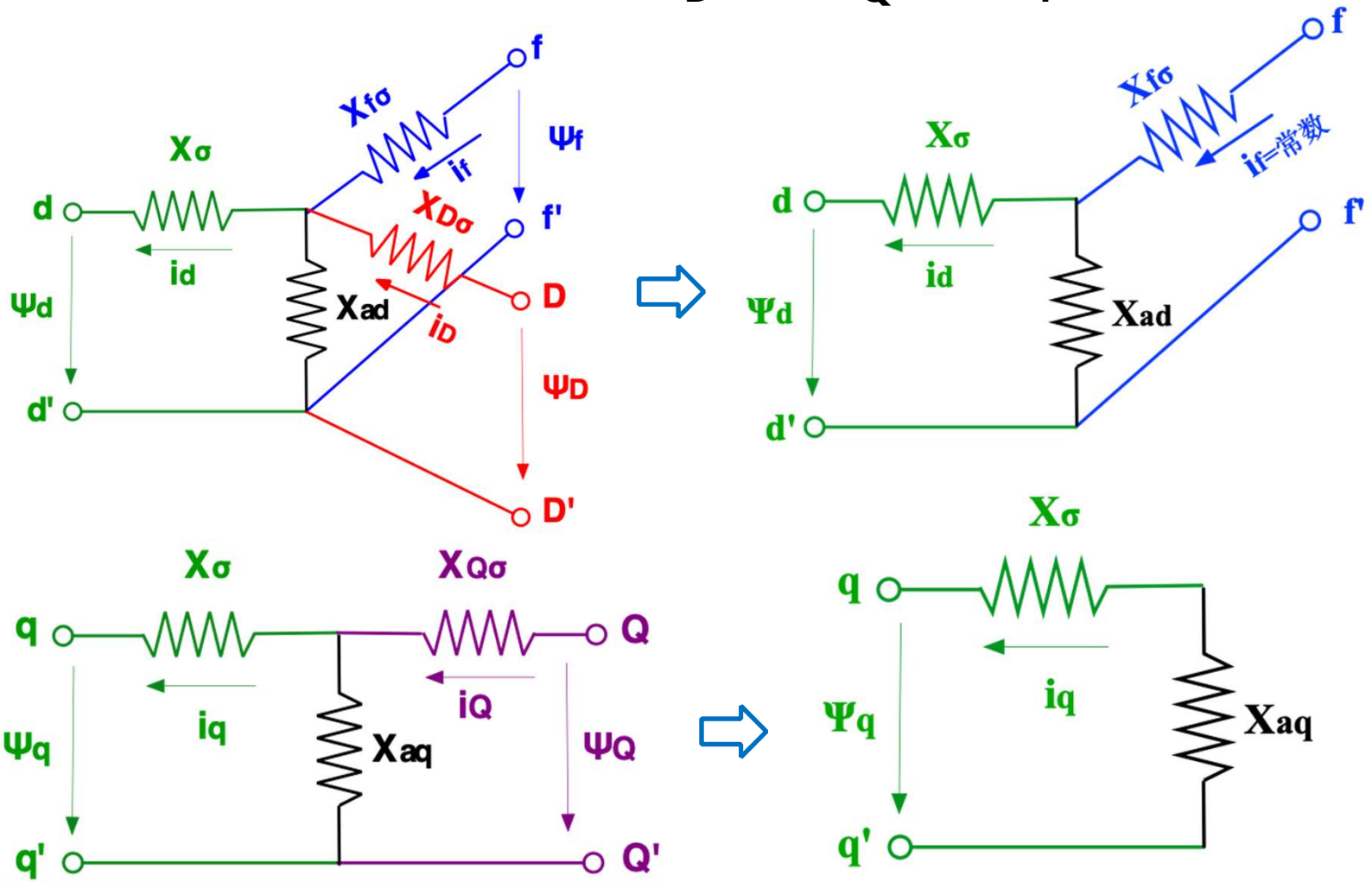


q轴磁链和电流的关系



派克变换的应用实例之二——发电机等值电路

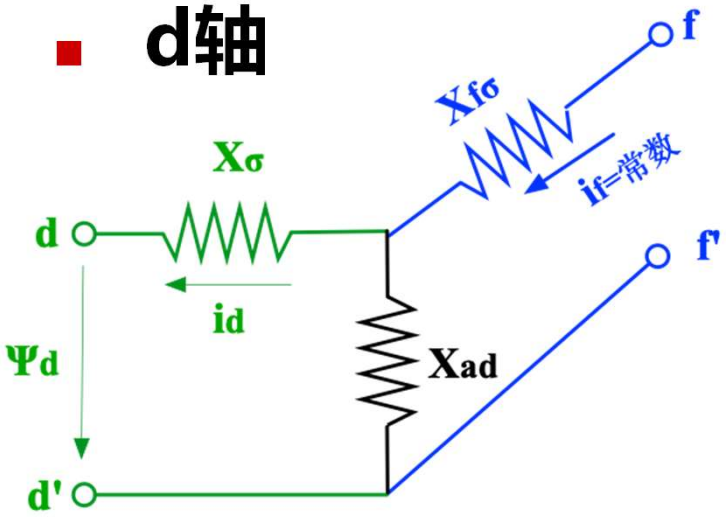
- 稳态等值电路 ⟹ $i_D=0$，$i_Q=0$，i_f=常数

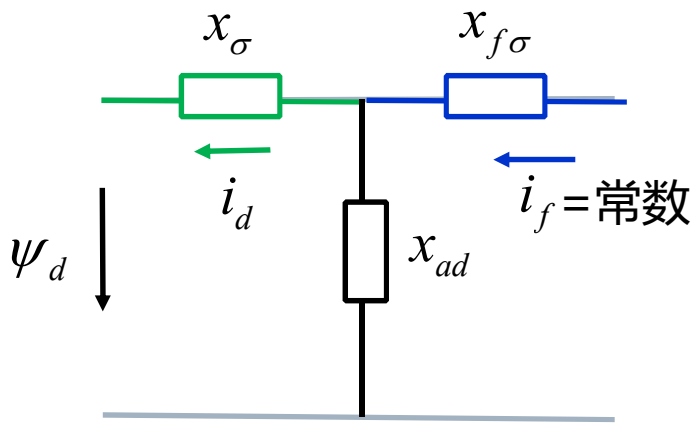


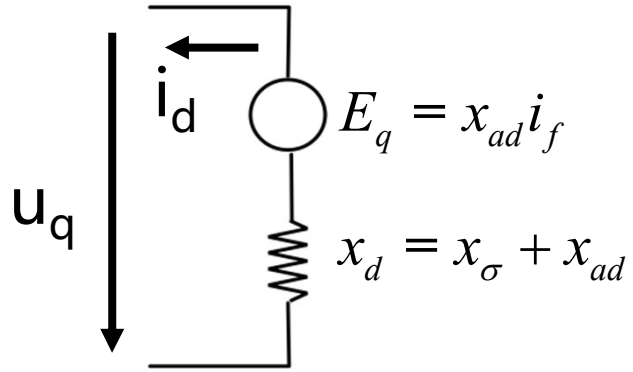
派克变换的应用实例之二——发电机等值电路

- 稳态等值电路 → $i_D=0$，$i_Q=0$，i_f=常数

- d轴

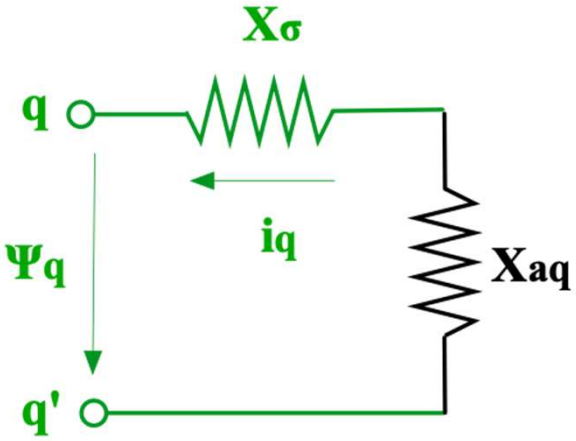


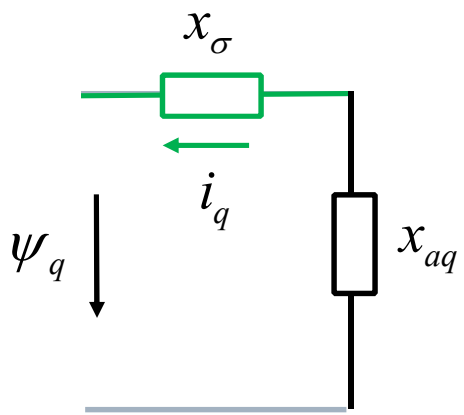


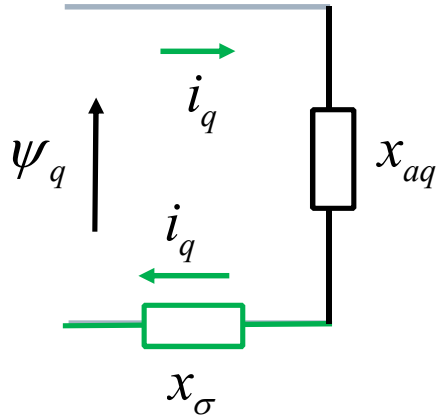


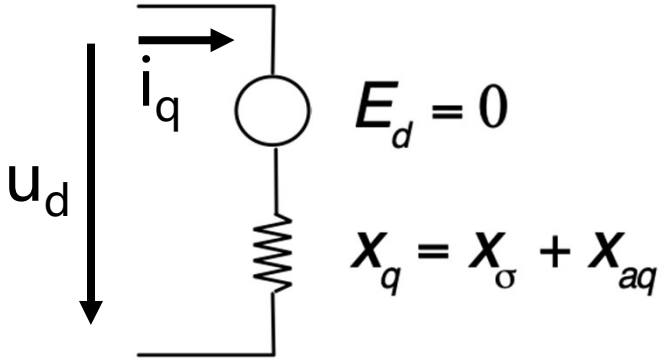
派克变换的应用实例之二——发电机等值电路

- 稳态等值电路 → $i_D=0$，$i_Q=0$，i_f=常数
  - q轴



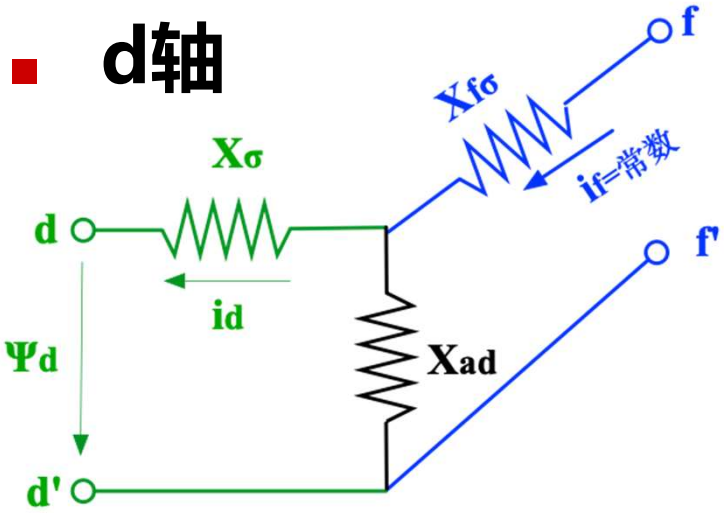


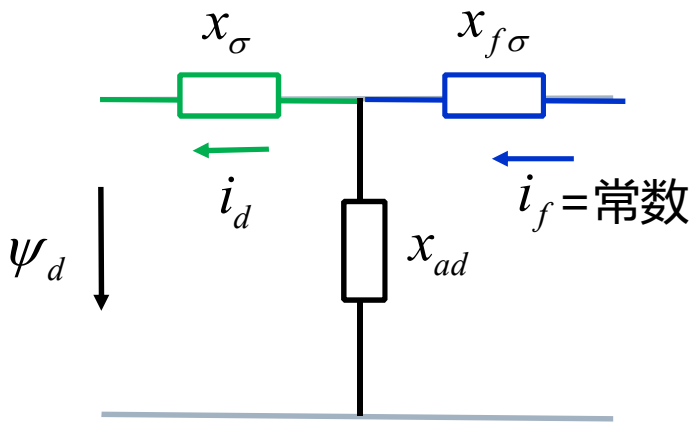


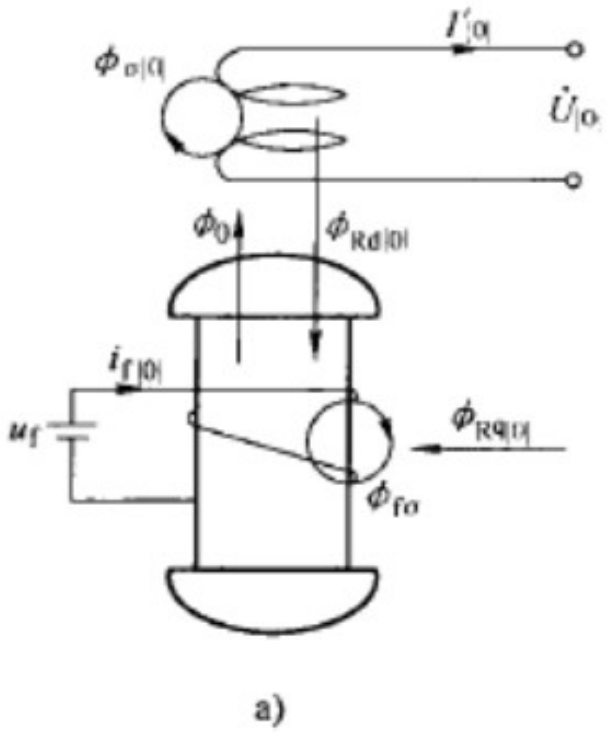


派克变换的应用实例之二——发电机等值电路

- 稳态等值电路 → $i_D=0$，$i_Q=0$，i_f=常数
  - d轴



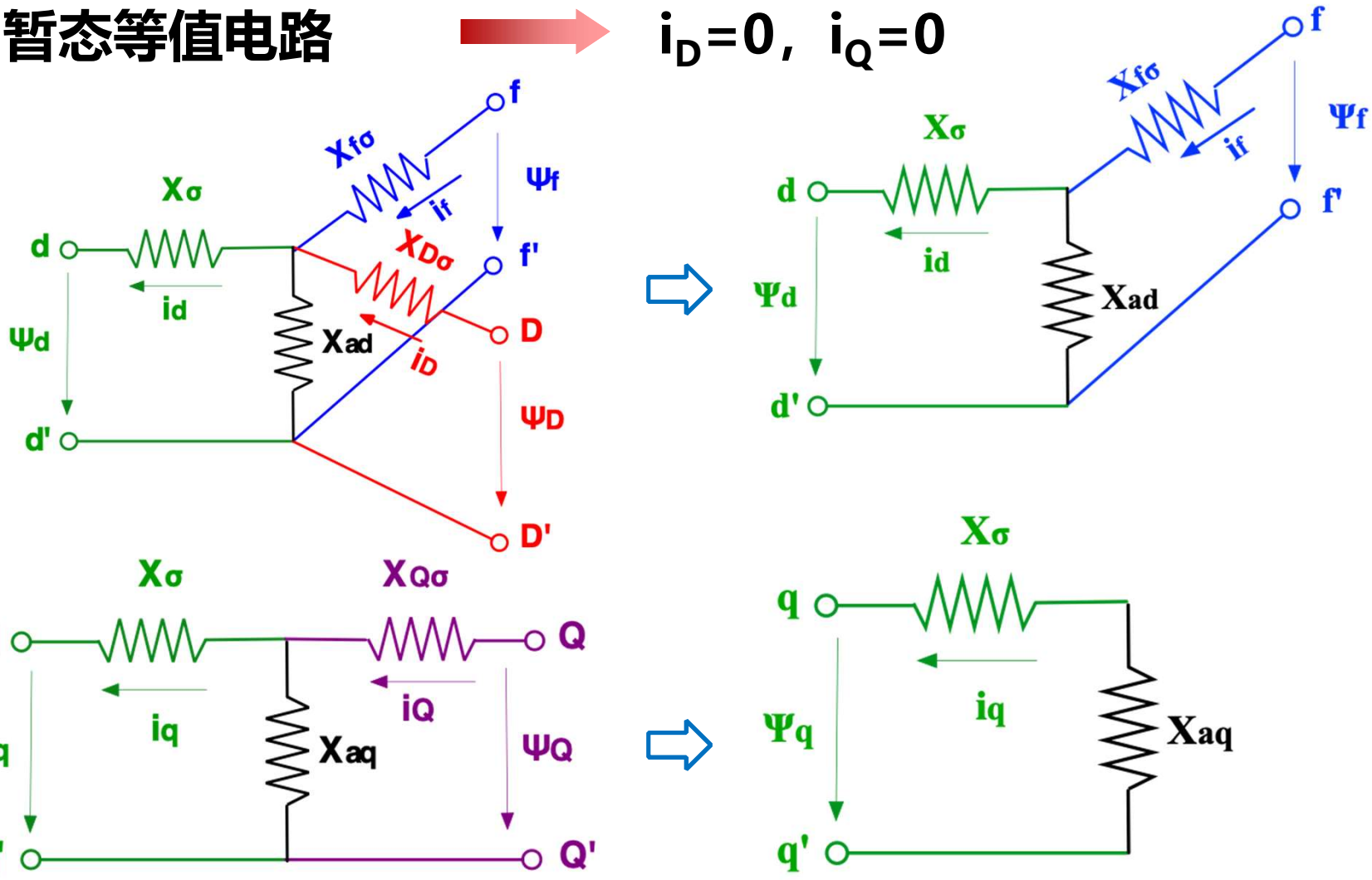




P10 图1-8

派克变换的应用实例之二——发电机等值电路

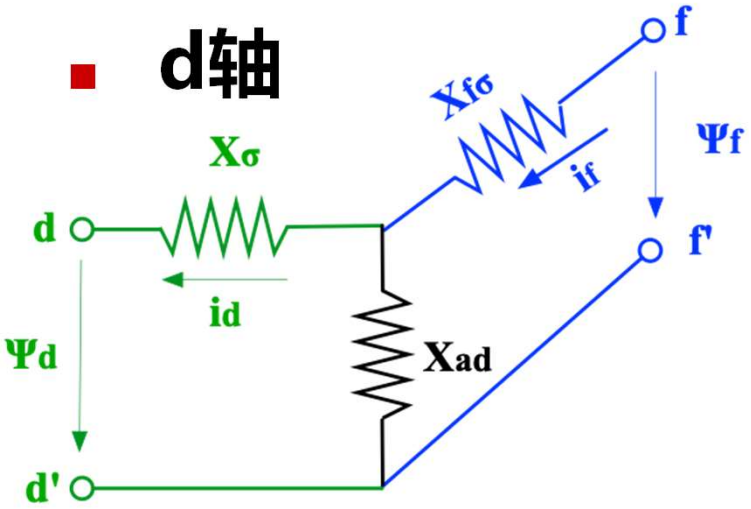
- 暂态等值电路 ⇒ $i_D=0$，$i_Q=0$

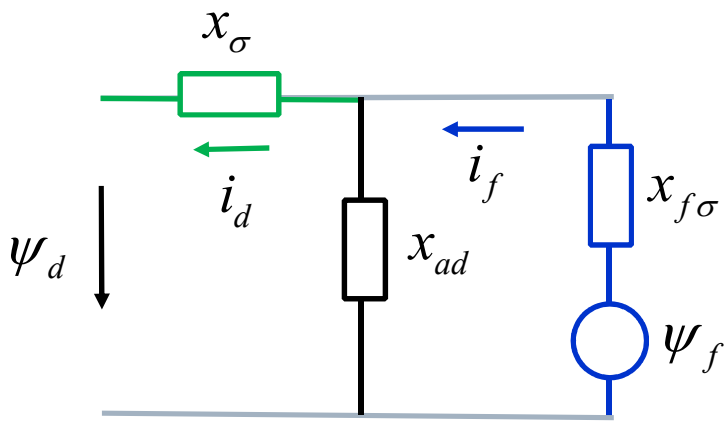


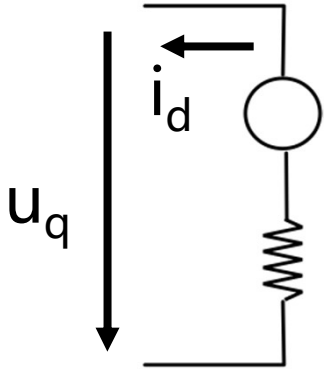
派克变换的应用实例之二——发电机等值电路

- 暂态等值电路 → $i_D=0$，$i_Q=0$

- d轴





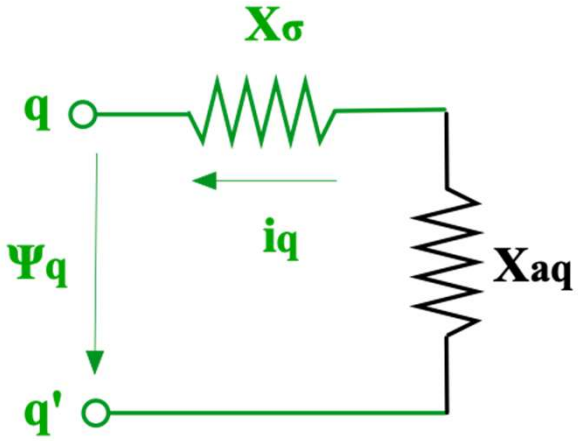


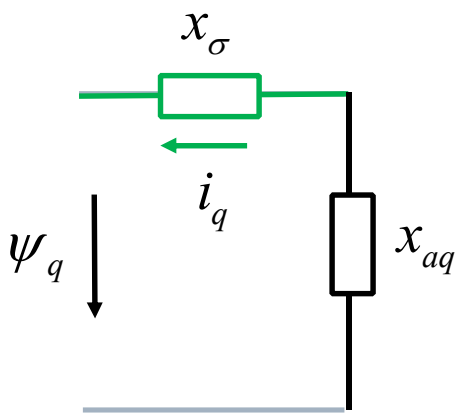
$$E'_q=\frac{x_{ad}}{x_{f\sigma}+x_{ad}}\psi_f=\frac{x_{ad}}{x_f}\psi_f$$

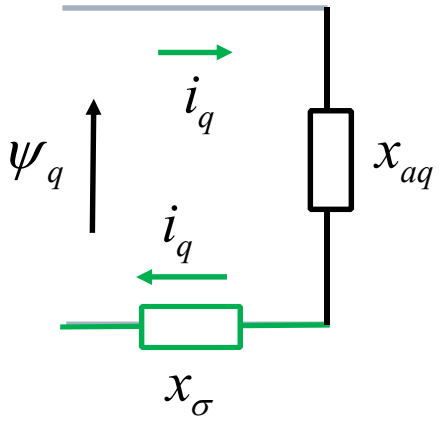
$$x'_d=x_\sigma+x_{ad}//x_{f\sigma}=x_\sigma+\frac{x_{ad}x_{f\sigma}}{x_{ad}+x_{f\sigma}}$$

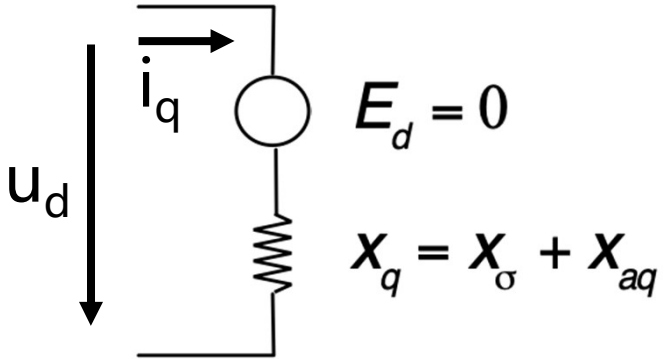
派克变换的应用实例之二——发电机等值电路

- 暂态等值电路 ⇒ $i_D=0$，$i_Q=0$
  - q轴（与稳态等值电路相同）



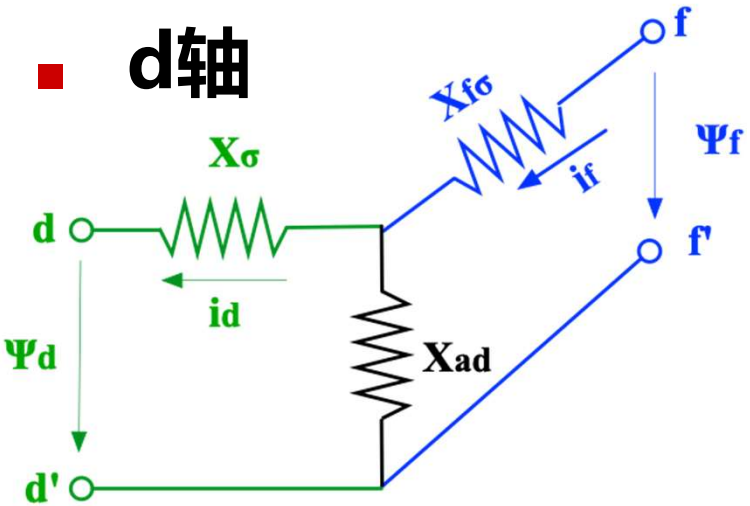


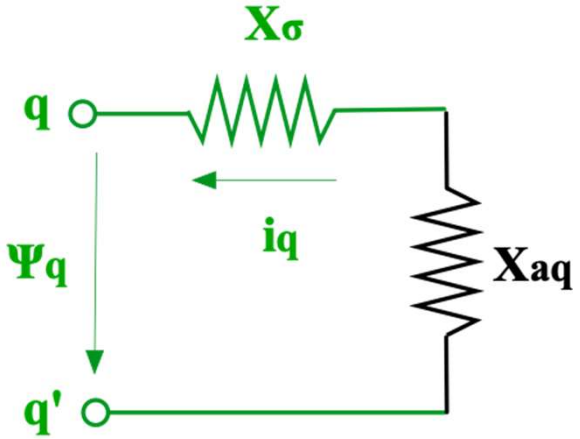


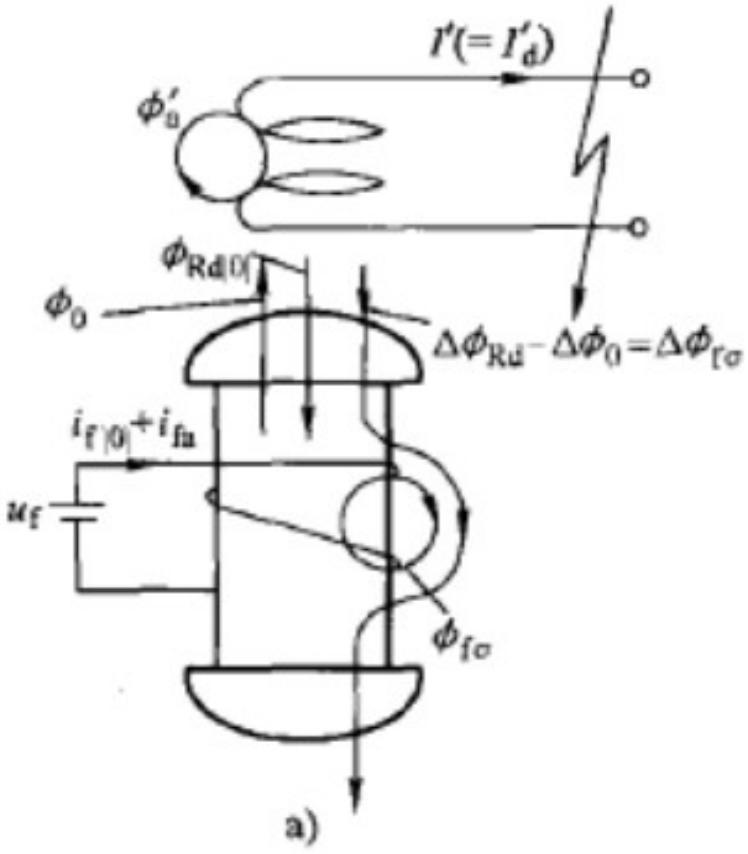


派克变换的应用实例之二——发电机等值电路

- 暂态等值电路 → $i_D=0$，$i_Q=0$
  - d轴





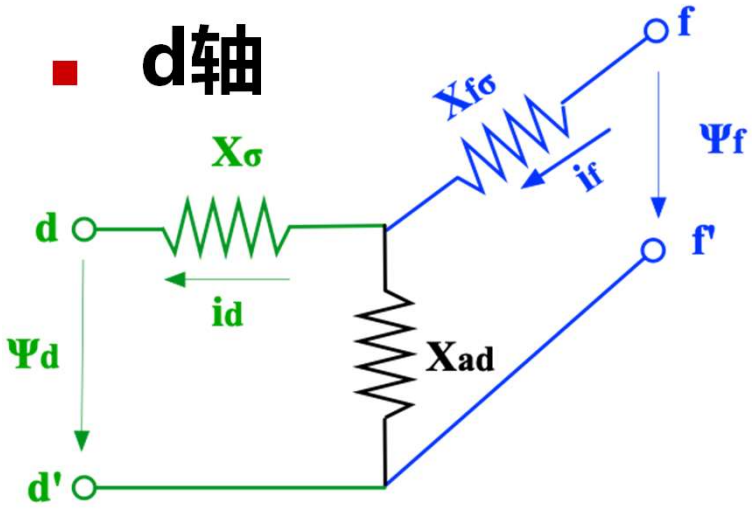


P11 图1-9

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



$$T_d' = \frac{x_{f-f'}}{R_f}$$

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

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

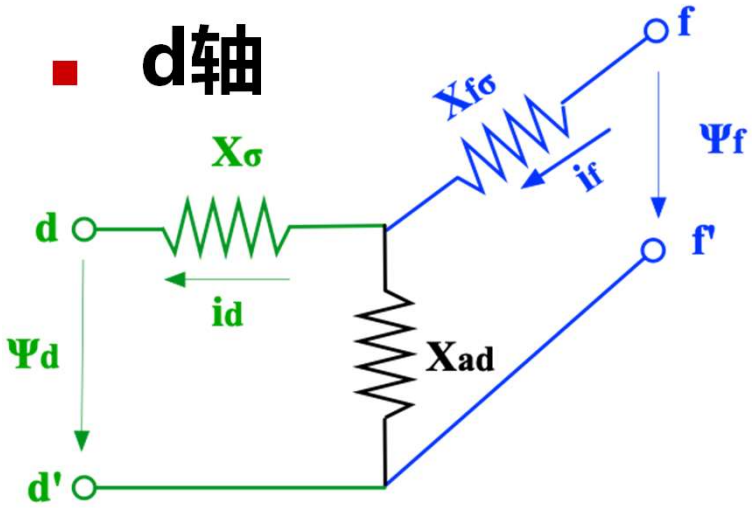
- 衰减时间常数（X/R）
  - Td'由f-f'等值参数确定
  - Ta由定子绕组等值参数确定

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

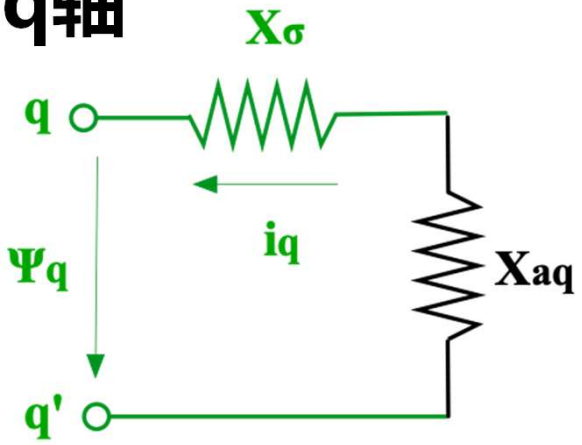
派克变换的应用实例之二——发电机等值电路

- 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

$$T_a=\frac{x_{eq}}{R_a}$$

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

$$x_q=x_\sigma+x_{aq}$$

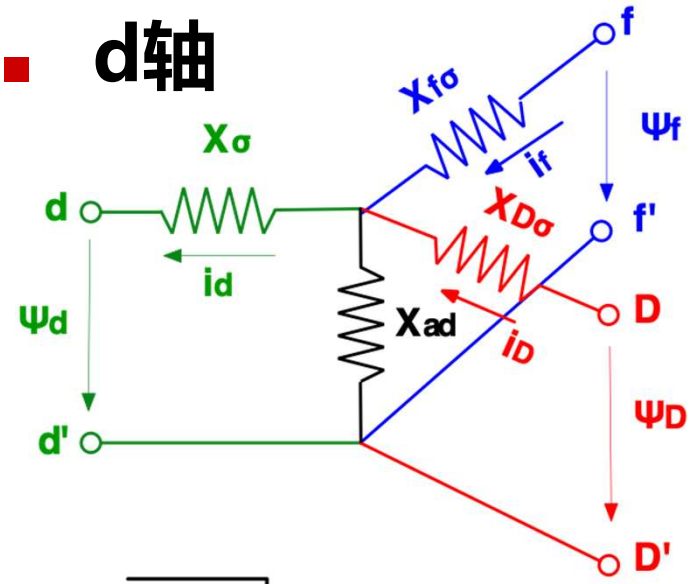
↓ 有效电抗

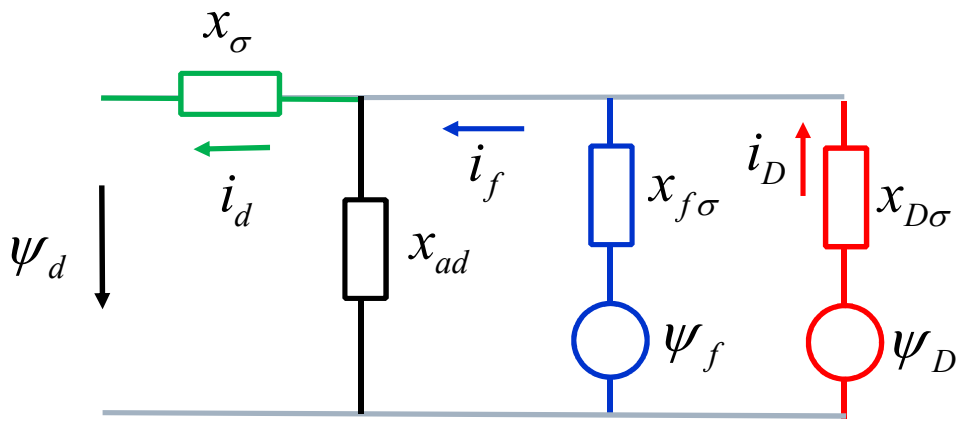
$$x_{eq}=\frac{2x'_dx_q}{x'_d+x_q}$$

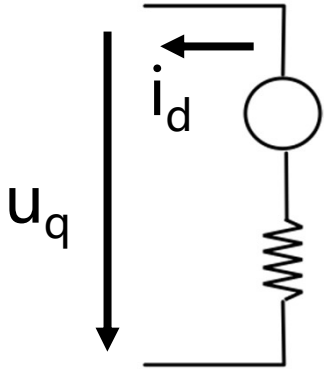
$$T_a=\left(\frac{2x'_dx_q}{x'_d+x_q}\right)\Big/R$$

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
  - d轴





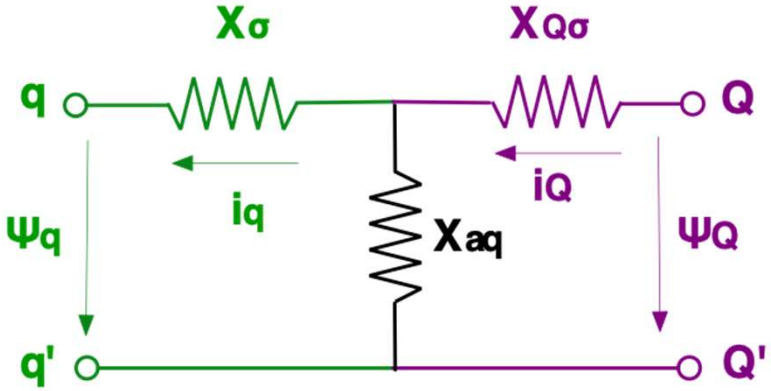


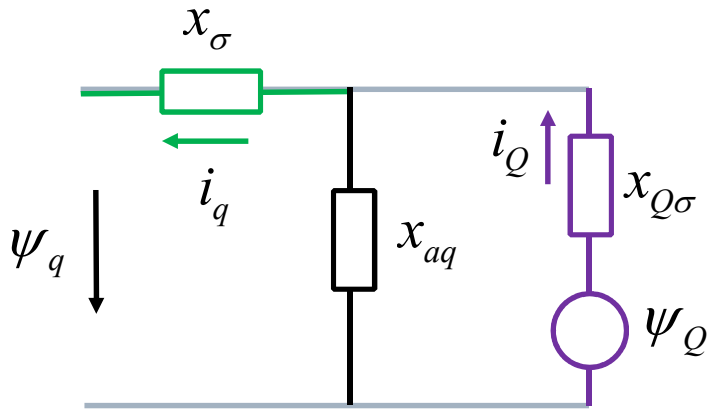
$$E''_q = \frac{x_{ad}//x_{D\sigma}}{x_{f\sigma}+x_{ad}//x_{D\sigma}}\psi_f + \frac{x_{ad}//x_{f\sigma}}{x_{D\sigma}+x_{ad}//x_{f\sigma}}\psi_D$$

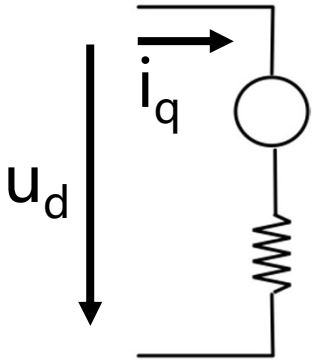
$$x''_d = x_\sigma + x_{ad}//x_{f\sigma}//x_{D\sigma} = x_\sigma + \frac{x_{ad}x_{f\sigma}x_{D\sigma}}{x_{ad}x_{f\sigma}+x_{ad}x_{D\sigma}+x_{f\sigma}x_{D\sigma}}$$

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
  - q轴





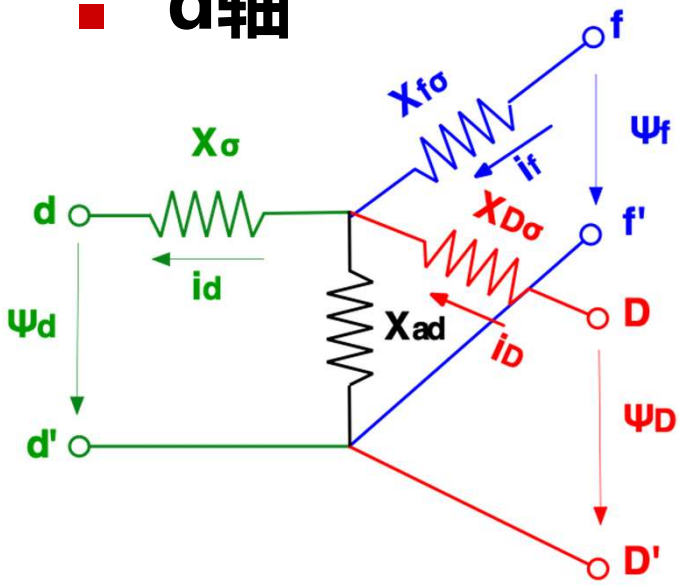


$$E_d'' = \frac{x_{aq}}{x_{Q\sigma} + x_{aq}} \psi_Q$$

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

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
  - d轴



$$T_d'' = \frac{x_{D-D'}}{R_D}$$

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

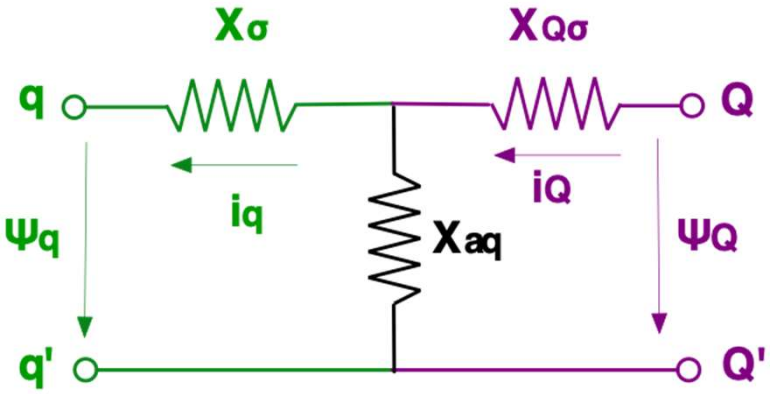
$$= x_{D\sigma} + \frac{x_\sigma x_{ad} x_{f\sigma}}{x_\sigma x_{ad} + x_{ad} x_{f\sigma} + x_\sigma x_{f\sigma}}$$

- 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

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

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
  - q轴



$$T_q'' = \frac{x_{Q-Q'}}{R_Q}$$

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

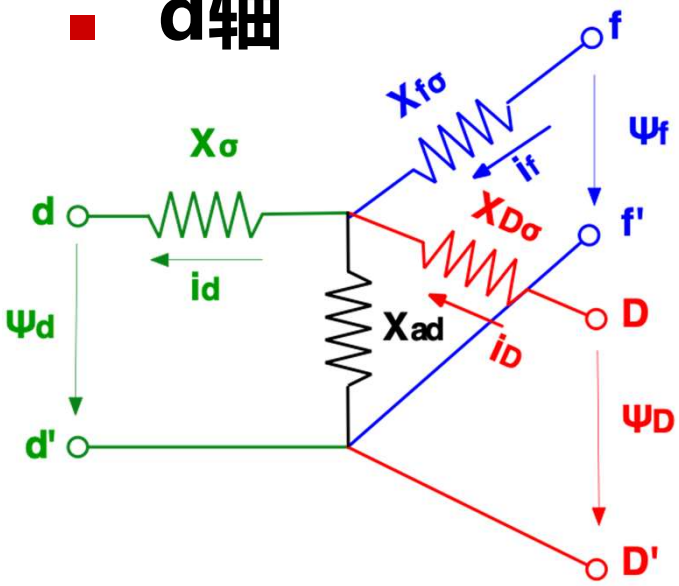
$$= x_{Q\sigma} + \frac{x_{aq} x_\sigma}{x_{aq} + x_\sigma}$$

- 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

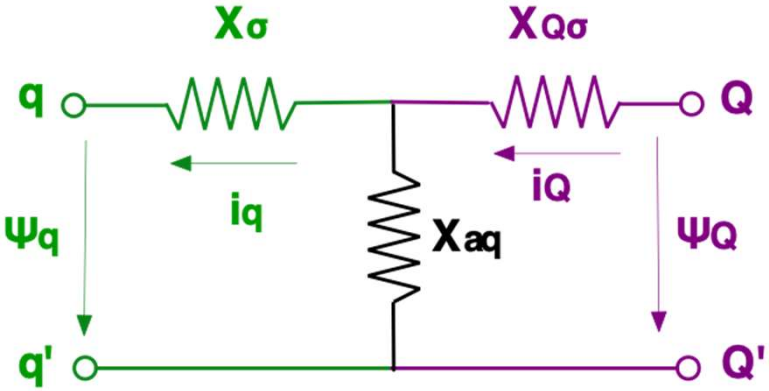
$$T_q'' = \left(x_{Q\sigma} + \frac{x_{aq} x_\sigma}{x_{aq} + x_\sigma} \right) \Big/ R_Q$$

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
  - d轴



  - q轴



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

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

⇩ 有效电抗

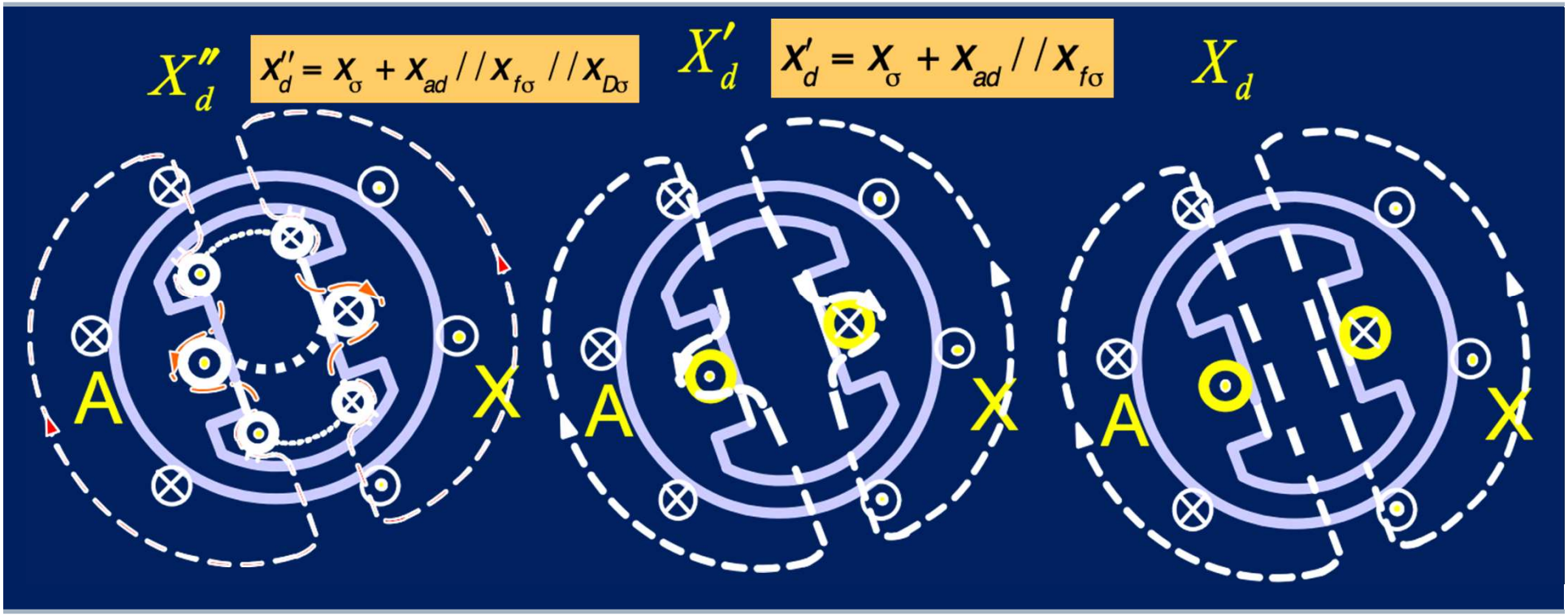
$$x_{eq} = \frac{2x_d'' x_q''}{x_d'' + x_q''}$$

- 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

$$T_a = \frac{x_{eq}}{R_a}$$

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

物理过程分析等值电抗



由于阻尼绕组的直流分量衰减较快，磁力线先从转子极靴处阻尼绕组进入主磁路，再逐渐从励磁绕组处完全进入主磁通。

《电机学》第十七章内容

第二次作业（等值电路及相量图）

- P64
  - 1-7，1-8

派克变换的应用实例之三

——发电机短路电流计算

派克变换的应用实例之三——发电机短路电流计算

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、电磁暂态过程中，转速维持同步速；

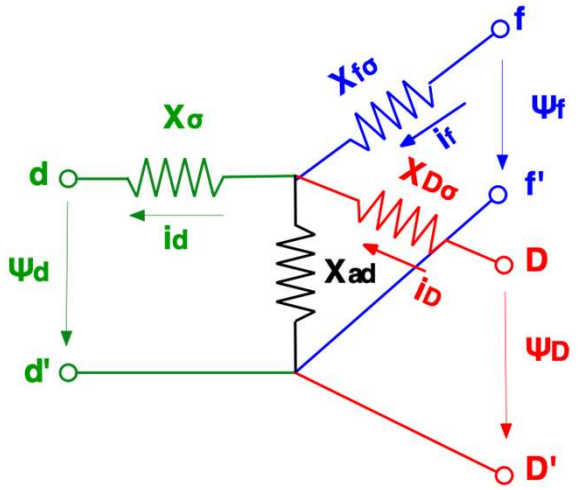
2、忽略定子回路的电磁暂态过程；

3、忽略定子电阻。

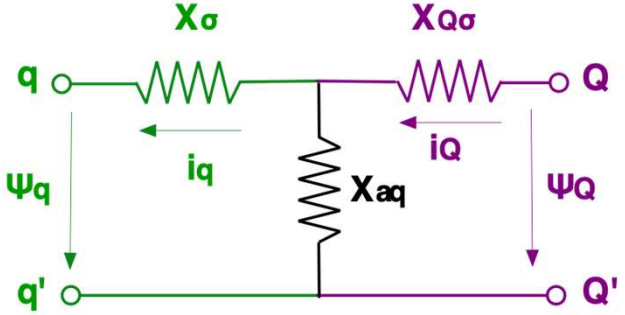
$$u_d = -\psi_q \qquad u_q = \psi_d$$

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

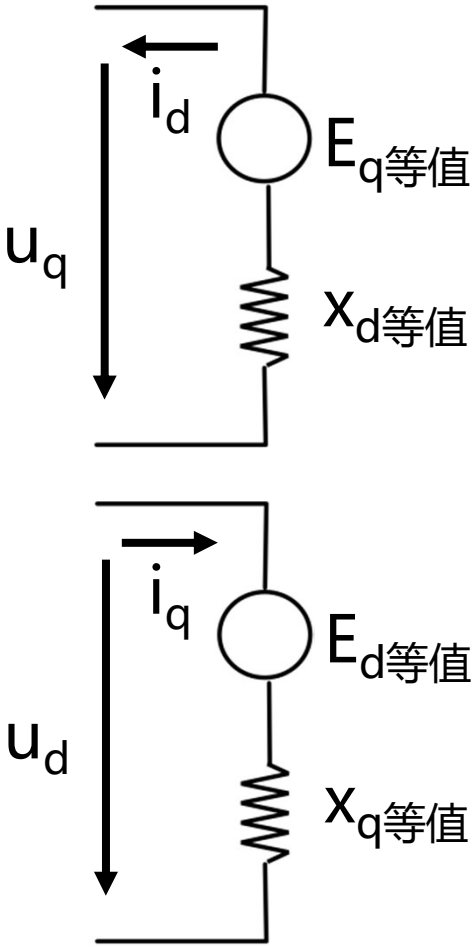


q轴磁链和电流的关系



派克变换的应用实例之三——发电机短路电流计算

- **发电机等值电路**



稳态

$$E_q = x_{ad}\left(-i_d + i_f\right) = x_{ad} i_f \qquad E_d = 0$$

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

暂态

$$E'_q = x_{ad}\left(-i_d + i_f\right) = \frac{x_{ad}}{x_{f\sigma} + x_{ad}}\psi_f \qquad E_d = 0$$

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

次暂态

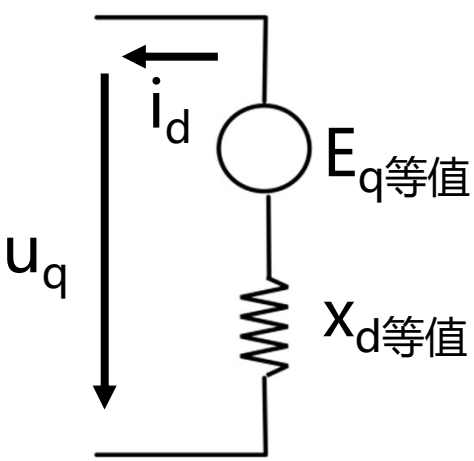
$$E''_q = x_{ad}\left(-i_d + i_f + i_D\right)$$

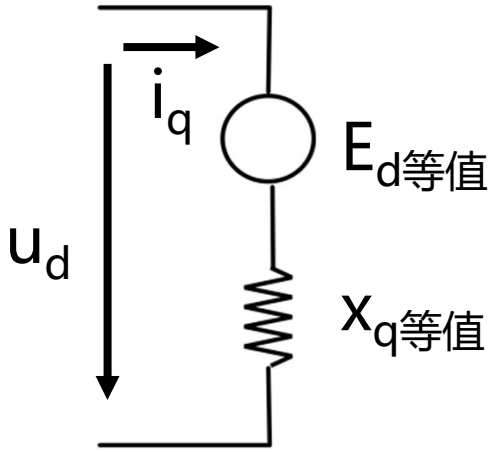
$$= \frac{x_{ad} // x_{D\sigma}}{x_{f\sigma} + x_{ad} // x_{D\sigma}}\psi_f + \frac{x_{ad} // x_{f\sigma}}{x_{D\sigma} + x_{ad} // x_{f\sigma}}\psi_D \qquad E''_d = \frac{Xaq}{X_{Q\sigma} + X_{aq}}\psi_Q$$

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

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	暂态	次暂态
$u_q = E_q - i_d x_d$	$u_q = E'_q - i_d x'_d$	$u_q = E''_q - i_d x''_d$
$u_d = E_d + i_q x_q = i_q x_q$	$u_d = E_d + i_q x_q = i_q x_q$	$u_d = E''_d + i_q x''_q$

空载情况下：各等值电势有什么关系？

发电机空载情况下，空载电动势、暂态电动势、次暂态电动势的关系：

A　空载电动势最大

B　暂态电动势最大

C　次暂态电动势最大

D　一样大

E　不确定