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  我的—最近看过—刘崇茹的课堂

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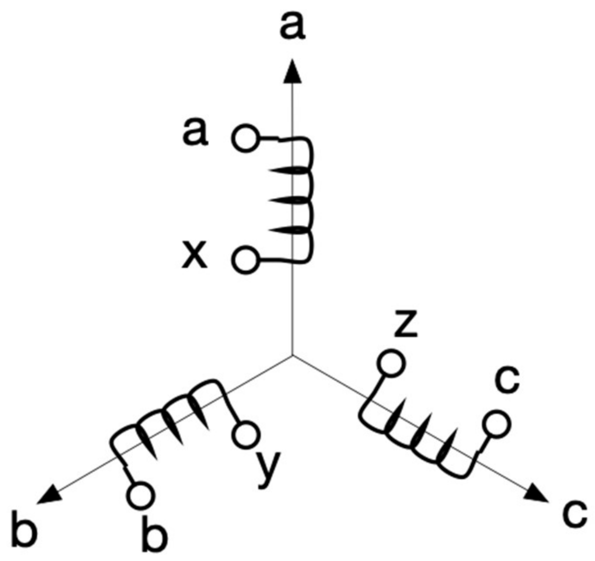
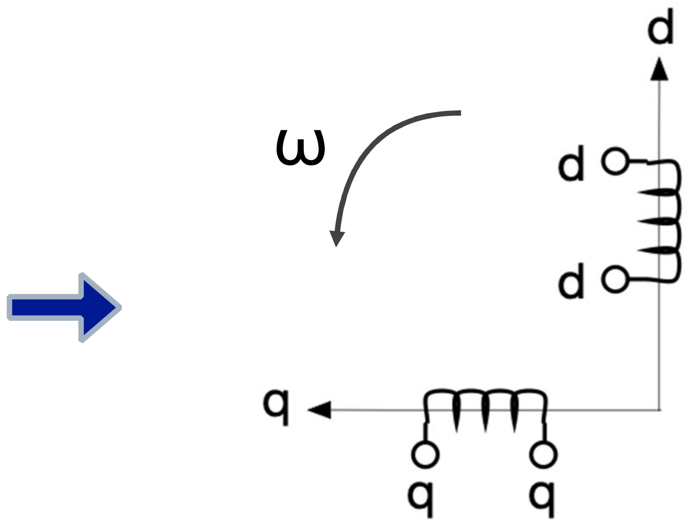
派克变换的原理

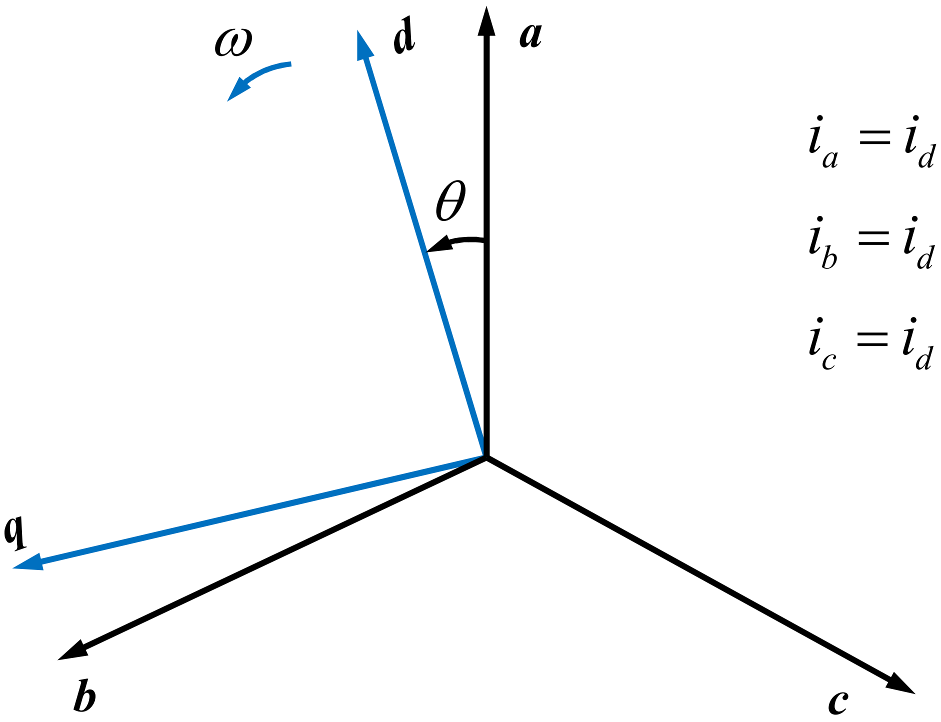
- 根据双反应原理，用直轴d、交轴q作为这两个轴线，并在这两个轴线方向分别放置一个等效定子绕组，用这两个等效的定子绕组所产生的电枢反应磁场来代替原来三相定子绕组所产生的电枢反应磁场。





关于基波磁动势和电流幅值的关系，可参考：https://zhuanlan.zhihu.com/p/77819897

派克变换的原理



$$i_a = i_d \cos\theta - i_q \sin\theta + i_0$$

$$i_b = i_d \cos(\theta - 120°) - i_q \sin(\theta - 120°) + i_0$$

$$i_c = i_d \cos(\theta + 120°) - i_q \sin(\theta + 120°) + i_0$$

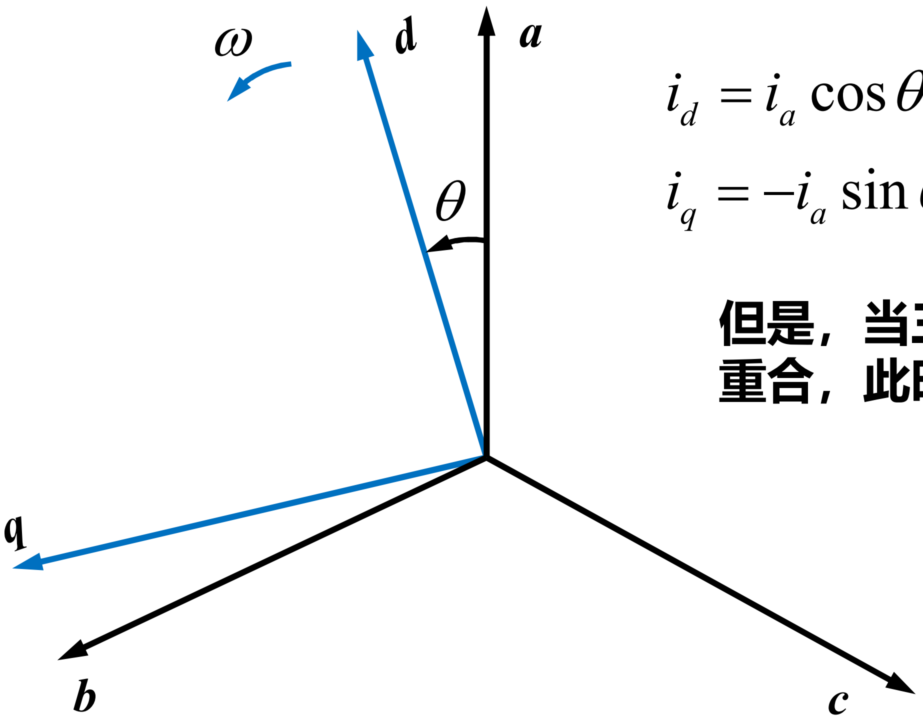
$$i_{abc} = P^{-1} i_{dq0}$$

对矩阵求逆，就可以得到P矩阵。

$$i_{dq0} = P i_{abc}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos(\theta - 120°) & -\sin(\theta - 120°) & 1 \\ \cos(\theta + 120°) & -\sin(\theta + 120°) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}$$

派克变换的原理



$$i_d = i_a \cos\theta + i_b \cos\left(\theta - 120^\circ\right) + i_c \cos\left(\theta + 120^\circ\right)$$

$$i_q = -i_a \sin\theta - i_b \sin\left(\theta - 120^\circ\right) - i_c \sin\left(\theta + 120^\circ\right)$$

但是，当三相电流只有正序且t=0时刻，d轴与a轴重合，此时a相电流达到最大值，则有：

$$i_a = I_m \cos\theta$$

$$i_b = I_m \cos\left(\theta - 120^\circ\right)$$

$$i_c = I_m \cos\left(\theta + 120^\circ\right)$$

$$i_d = I_m \cos^2\theta + I_m \cos^2\left(\theta - 120^\circ\right) + I_m \cos^2\left(\theta + 120^\circ\right) = \frac{3}{2} I_m$$

$$i_q = 0$$

因此变换矩阵要取一个系数2/3，以使得合成的空间综合矢量数值上仍为1。

派克变换

- **正变换：abc->dq0**

$$A_{dq0} = PA_{abc}$$

$$P = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - 120^o\right) & \cos\left(\theta + 120^o\right) \\ -\sin\theta & -\sin\left(\theta - 120^o\right) & -\sin\left(\theta + 120^o\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

- **反变换：dq0-> abc**

$$A_{abc} = P^{-1} A_{dq0}$$

$$P^{-1} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - 120^o\right) & -\sin\left(\theta - 120^o\right) & 1 \\ \cos\left(\theta + 120^o\right) & -\sin\left(\theta + 120^o\right) & 1 \end{bmatrix}$$

对磁链方程进行派克变换

$$\begin{bmatrix} \boldsymbol{\psi}_{abc} \\ \boldsymbol{\psi}_{fDQ} \end{bmatrix} = \begin{bmatrix} \boldsymbol{M}_{SS} & \boldsymbol{M}_{SR} \\ \boldsymbol{M}_{RS} & \boldsymbol{M}_{RR} \end{bmatrix} \begin{bmatrix} -\boldsymbol{I}_{abc} \\ \boldsymbol{I}_{fDQ} \end{bmatrix}$$

$$A_{dq0} = PA_{abc}$$

$$\begin{pmatrix} \psi_a \\ \psi_b \\ \psi_c \\ \cdots \\ \psi_f \\ \psi_D \\ \psi_Q \end{pmatrix} = \begin{pmatrix} L_{aa} & M_{ab} & M_{ac} & \vdots & M_{af} & M_{aD} & M_{aQ} \\ M_{ba} & L_{bb} & M_{bc} & \vdots & M_{bf} & M_{bD} & M_{bQ} \\ M_{ca} & M_{cb} & L_{cc} & \vdots & M_{cf} & M_{cD} & M_{cQ} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ M_{fa} & M_{fb} & M_{fc} & \vdots & L_{ff} & M_{fD} & M_{fQ} \\ M_{Da} & M_{Db} & M_{Dc} & \vdots & M_{Df} & L_{DD} & M_{DQ} \\ M_{Qa} & M_{Qb} & M_{Qc} & \vdots & M_{Qf} & M_{QD} & L_{QQ} \end{pmatrix} \begin{pmatrix} -i_a \\ -i_b \\ -i_c \\ \cdots \\ i_f \\ i_D \\ i_Q \end{pmatrix}$$

派克变换后——磁链方程

- **磁链方程**

$$\begin{pmatrix} \psi_{\mathrm{d}} \\ \psi_{\mathrm{q}} \\ \psi_0 \\ \cdots \\ \psi_{\mathrm{f}} \\ \psi_{\mathrm{D}} \\ \psi_{\mathrm{Q}} \end{pmatrix} = \begin{pmatrix} L_{\mathrm{d}} & 0 & 0 & \vdots & m_{\mathrm{af}} & m_{\mathrm{aD}} & 0 \\ 0 & L_{\mathrm{q}} & 0 & \vdots & 0 & 0 & m_{\mathrm{aQ}} \\ 0 & 0 & L_0 & \vdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \vdots & \cdots & \cdots & \cdots \\ \frac{3}{2}m_{\mathrm{af}} & 0 & 0 & \vdots & L_{\mathrm{f}} & m_{\mathrm{r}} & 0 \\ \frac{3}{2}m_{\mathrm{aD}} & 0 & 0 & \vdots & m_{\mathrm{r}} & L_{\mathrm{D}} & 0 \\ 0 & \frac{3}{2}m_{\mathrm{aQ}} & 0 & \vdots & 0 & 0 & L_{\mathrm{Q}} \end{pmatrix} \cdot \begin{pmatrix} -i_{\mathrm{d}} \\ -i_{\mathrm{q}} \\ -i_0 \\ \cdots \\ i_{\mathrm{f}} \\ i_{\mathrm{D}} \\ i_{\mathrm{Q}} \end{pmatrix}$$

派克变换后——磁链方程

■ 数学处理

$$
\begin{pmatrix} \psi_{\mathrm{d}} \\ \psi_{\mathrm{q}} \\ \psi_{0} \\ \cdots \\ \psi_{\mathrm{f}} \\ \psi_{\mathrm{D}} \\ \psi_{\mathrm{Q}} \end{pmatrix}
=
\begin{pmatrix}
L_{\mathrm{d}} & 0 & 0 & \vdots & \frac{3}{2}m_{\mathrm{af}} & \frac{3}{2}m_{\mathrm{aD}} & 0 \\
0 & L_{\mathrm{q}} & 0 & \vdots & 0 & 0 & \frac{3}{2}m_{\mathrm{aQ}} \\
0 & 0 & L_{0} & \vdots & 0 & 0 & 0 \\
\cdots & \cdots & \cdots & \vdots & \cdots & \cdots & \cdots \\
\frac{3}{2}m_{\mathrm{af}} & 0 & 0 & \vdots & \frac{3}{2}L_{\mathrm{f}} & \frac{3}{2}m_{\mathrm{r}} & 0 \\
\frac{3}{2}m_{\mathrm{aD}} & 0 & 0 & \vdots & \frac{3}{2}m_{\mathrm{r}} & \frac{3}{2}L_{\mathrm{D}} & 0 \\
0 & \frac{3}{2}m_{\mathrm{aQ}} & 0 & \vdots & 0 & 0 & \frac{3}{2}L_{\mathrm{Q}}
\end{pmatrix}
\cdot
\begin{pmatrix} -i_{\mathrm{d}} \\ -i_{\mathrm{q}} \\ -i_{0} \\ \cdots \\ \frac{2}{3}i_{\mathrm{f}} \\ \frac{2}{3}i_{\mathrm{D}} \\ \frac{2}{3}i_{\mathrm{Q}} \end{pmatrix}
$$

派克变换后——磁链方程

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

$$\boxed{x_{aD} = x_{fD} = x_{ad}}$$

$$\boxed{x_{aQ} = x_{aq}}$$

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

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

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

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

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

派克变换后——磁链方程

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

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

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

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

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

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

同步发电机的基本方程

$$\begin{pmatrix} u_d \\ u_q \\ u_0 \\ \cdots \\ u_f \\ 0 \\ 0 \end{pmatrix} = \left(\begin{array}{ccc:ccc} R & & & & 0 & \\ & R & & & & \\ & & R & & & \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ & & & R_f & & \\ & 0 & & & R_D & \\ & & & & & R_Q \end{array}\right) \begin{pmatrix} -i_d \\ -i_q \\ -i_0 \\ \cdots \\ i_f \\ i_D \\ i_Q \end{pmatrix} + \begin{pmatrix} p\psi_d \\ p\psi_q \\ p\psi_0 \\ \cdots \\ p\psi_f \\ p\psi_D \\ p\psi_Q \end{pmatrix} - \begin{pmatrix} (1+s)\psi_q \\ -(1+s)\psi_d \\ 0 \\ \cdots \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

以dq0坐标系统表示的同步发电机的电压方程，一般称为派克方程。

$$\begin{pmatrix} \psi_d \\ \psi_q \\ \psi_0 \\ \cdots \\ \psi_f \\ \psi_D \\ \psi_Q \end{pmatrix} = \left(\begin{array}{ccc:ccc} X_d & 0 & 0 & X_{ad} & X_{ad} & 0 \\ 0 & X_q & 0 & 0 & 0 & X_{aq} \\ 0 & 0 & X_0 & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{ad} & 0 & 0 & X_f & X_{ad} & 0 \\ X_{ad} & 0 & 0 & X_{ad} & X_D & 0 \\ 0 & X_{aq} & 0 & 0 & 0 & X_Q \end{array}\right) \begin{pmatrix} -i_d \\ -i_q \\ -i_0 \\ \cdots \\ i_f \\ i_D \\ i_Q \end{pmatrix}$$

经派克变换后的同步发电机磁链、电压方程称为同步发电机的基本方程。

派克变换的应用实例之一——发电机运行相量图

- **简化：**
  - **三相对称** $u_0=0, \ i_0=0, \ \Psi_0=0$
  - **阻尼绕组** $i_D=0, \ i_Q=0$

$$
\begin{pmatrix} u_d \\ u_q \\ u_0 \\ \cdots \\ u_f \\ 0 \\ 0 \end{pmatrix}
=
\left(\begin{array}{ccc:ccc}
R & & & & & \\
 & R & & & 0 & \\
 & & R & & & \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
 & & & R_f & & \\
 & 0 & & & R_D & \\
 & & & & & R_Q
\end{array}\right)
\begin{pmatrix} -i_d \\ -i_q \\ -i_0 \\ \cdots \\ i_f \\ i_D \\ i_Q \end{pmatrix}
+
\begin{pmatrix} p\psi_d \\ p\psi_q \\ p\psi_0 \\ \cdots \\ p\psi_f \\ p\psi_D \\ p\psi_Q \end{pmatrix}
-
\begin{pmatrix} (1+s)\psi_q \\ -(1+s)\psi_d \\ 0 \\ \cdots \\ 0 \\ 0 \\ 0 \end{pmatrix}
$$

$$
\boxed{
\begin{aligned}
u_d &= -r_a i_d + \dot{\psi}_d - \omega\psi_q \\
u_q &= -r_a i_q + \dot{\psi}_q + \omega\psi_d \\
u_f &= r_f i_f + \dot{\psi}_f
\end{aligned}
}
$$

派克变换的应用实例之一——发电机运行相量图

- **简化：**
  - 三相对称 $u_0=0,\ i_0=0,\ \Psi_0=0$
  - 阻尼绕组 $i_D=0,\ i_Q=0$

$$
\begin{pmatrix} \psi_d \\ \psi_q \\ \psi_0 \\ \cdots \\ \psi_f \\ \psi_D \\ \psi_Q \end{pmatrix}
=
\begin{pmatrix}
X_d & 0 & 0 & \vdots & X_{ad} & X_{ad} & 0 \\
0 & X_q & 0 & \vdots & 0 & 0 & X_{aq} \\
0 & 0 & X_0 & \vdots & 0 & 0 & 0 \\
\cdots & \cdots & \cdots & \vdots & \cdots & \cdots & \cdots \\
X_{ad} & 0 & 0 & \vdots & X_f & X_{ad} & 0 \\
X_{ad} & 0 & 0 & \vdots & X_{ad} & X_D & 0 \\
0 & X_{aq} & 0 & \vdots & 0 & 0 & X_Q
\end{pmatrix}
\begin{pmatrix} -i_d \\ -i_q \\ -i_0 \\ \cdots \\ i_f \\ i_D \\ i_Q \end{pmatrix}
\Rightarrow
\boxed{
\begin{aligned}
\psi_d &= -x_d i_d + x_{ad} i_f \\
\psi_q &= -x_q i_q \\
\psi_f &= -x_{ad} i_d + x_f i_f
\end{aligned}
}
$$

派克变换的应用实例之一——发电机运行相量图

$$u_d = -r_a i_d + \dot{\psi}_d - \omega\psi_q \qquad \psi_d = -x_d i_d + x_{ad} i_f$$

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

$$u_f = r_f i_f + \dot{\psi}_f \qquad \psi_f = -x_{ad} i_d + x_f i_f$$

- **假设:**
  - **忽略定子绕组内部电磁暂态过程，pΨ均为零**
  - **忽略转子转速变化，ω=1**

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

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

$$\Rightarrow$$

$$u_d = -r_a i_d + x_q i_q$$

$$u_q = -r_a i_q - x_d i_d + x_{ad} i_f$$

- **空载:**
  - **电枢电流为零，$i_d=0$，$i_q=0$**

$$u_d = -r_a i_d + x_q i_q$$

$$u_q = -r_a i_q - x_d i_d + x_{ad} i_f$$

$$\Rightarrow$$

$$u_d = 0$$

$$u_q = x_{ad} i_f$$

定义为
空载电动势Eq
Eq在q轴上

派克变换的应用实例之一——发电机运行相量图

$$u_d = -r_a i_d + x_q i_q$$
$$u_q = -r_a i_q - x_d i_d + x_{ad} i_f$$

$$u_d = -r_a i_d + x_q i_q$$
$$u_q = -r_a i_q - x_d i_d + E_q$$

- 设d轴为实轴方向：
  - 那么，q轴则为虚轴方向，用d-q坐标系描述，则有

$$\begin{cases} \dot{U}_d = u_d \\ \dot{U}_q = ju_q \\ \dot{E}_q = jE_q \end{cases}$$

$$\begin{cases} \dot{I}_d = i_d \\ \dot{I}_q = ji_q \end{cases}$$

$$u_d = \dot{U}_d = -r_a i_d + x_q i_q = -r_a \dot{I}_d + x_q\left(\frac{\dot{I}_q}{j}\right) = -r_a \dot{I}_d - jx_q \dot{I}_q$$

$$u_q = \left(\frac{\dot{U}_q}{j}\right) = -r_a\left(\frac{\dot{I}_q}{j}\right) - x_d \dot{I}_d + \left(\frac{\dot{E}_q}{j}\right)$$

$$\boxed{\begin{aligned} \dot{U}_d &= -r_a \dot{I}_d - jx_q \dot{I}_q \\ \dot{U}_q &= -r_a \dot{I}_q - jx_d \dot{I}_d + \dot{E}_q \end{aligned}}$$

派克变换的应用实例之一——发电机运行相量图

- **相量形式：**

$$\dot{U}_d = -r_a \dot{I}_d - jx_q \dot{I}_q$$
$$\dot{U}_q = -r_a \dot{I}_q - jx_d \dot{I}_d + \dot{E}_q$$

$$\dot{U} = \dot{U}_d + \dot{U}_q = -r_a\left(\dot{I}_d + \dot{I}_q\right) - jx_q \dot{I}_q - jx_d \dot{I}_d + \dot{E}_q$$

$$\dot{E}_q = \dot{U} + r_a \dot{I} + jx_q \dot{I}_q + jx_d \dot{I}_d$$

隐极机（$x_d = x_q$）

$$\dot{E}_q = \dot{U} + r_a \dot{I} + jx_d\left(\dot{I}_q + \dot{I}_d\right) = \dot{U} + r_a \dot{I} + jx_d \dot{I}$$

凸极机（$x_d > x_q$）

$$\dot{E}_q = \dot{U} + r\dot{I} + jx_d \dot{I}_d + jx_q \dot{I}_q = \dot{U} + r\dot{I} + jx_q \dot{I} + j\left(x_d - x_q\right)\dot{I}_d$$

派克变换的应用实例之一——发电机运行相量图

隐极机（$x_d=x_q$）

$$\dot{E}_q = \dot{U} + r_a\dot{I} + jx_d\left(\dot{I}_q + \dot{I}_d\right) = \dot{U} + r_a\dot{I} + jx_d\dot{I}$$

$$\dot{E}_q = \dot{U} + r\dot{I} + jx_d\dot{I}_d + jx_q\dot{I}_q = \dot{U} + r\dot{I} + jx_q\dot{I} + j\left(x_d - x_q\right)\dot{I}_d$$

对隐极机同样成立

$$\boxed{\begin{aligned}\dot{E}_Q &= \dot{U} + r\dot{I} + jx_q\dot{I} \\ \dot{E}_q &= \dot{E}_Q + j\left(x_d - x_q\right)\dot{I}_d\end{aligned}}$$

对凸极机来说，E_Q是个虚构电势，本身并不存在

对凸极机来说，E_Q的作用是定位d-q轴

派克变换的应用实例之一——发电机运行相量图

如何根据这个方程绘制相量图？

$$\dot{E}_Q = \dot{U} + r\dot{I} + jx_q\dot{I}$$

$$\dot{E}_q = \dot{E}_Q + j\left(x_d - x_q\right)\dot{I}_d$$

派克变换的应用实例之二

——发电机等值电路

派克变换的应用实例之二——发电机等值电路

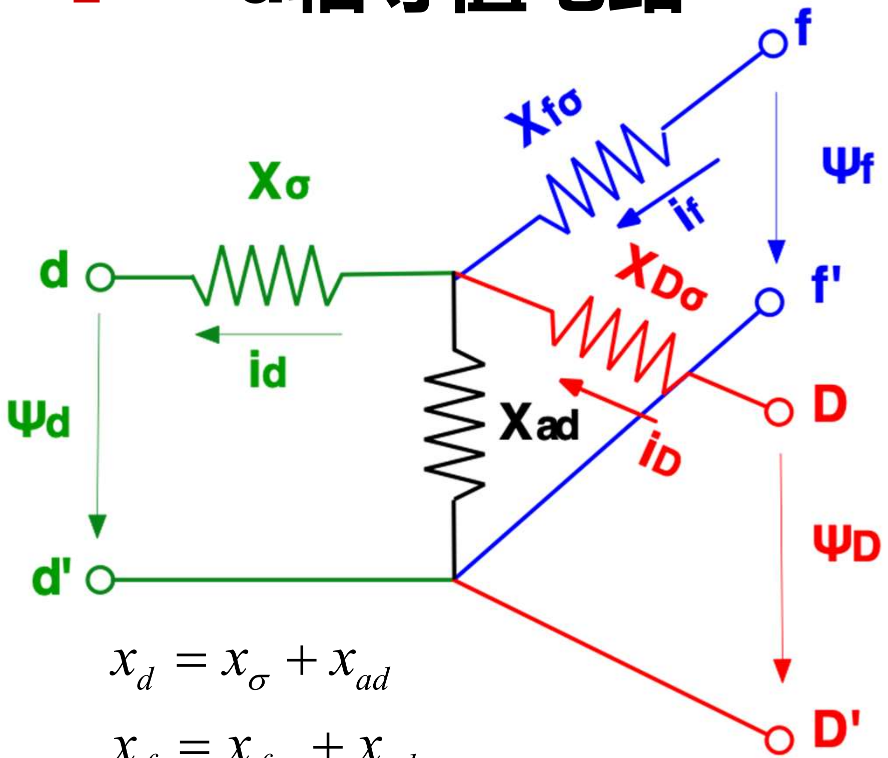
- 将发电机等值成变压器
  - 直轴上，励磁绕组f、直轴等值阻尼绕组D和定子等值直轴绕组d组成三绕组变压器
  - 交轴上，交轴等值阻尼绕组Q和定子交轴等值绕组q组成双绕组变压器，从而简化了模型并便于求解。

- 仿照变压器的等值电路
  - d轴——三绕组变压器
  - q轴——双绕组变压器

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

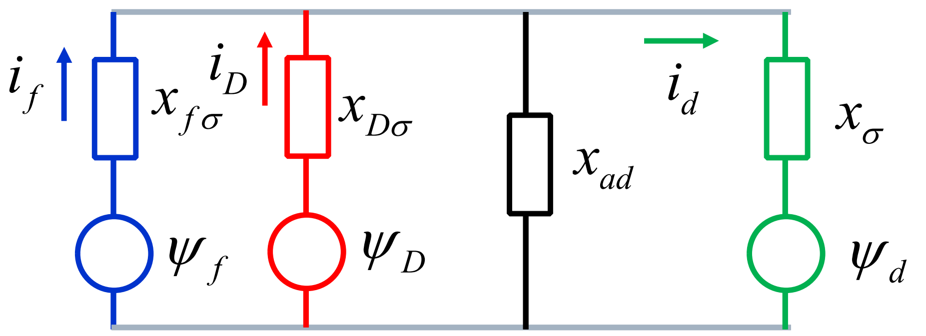


$$x_d = x_\sigma + x_{ad}$$

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

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

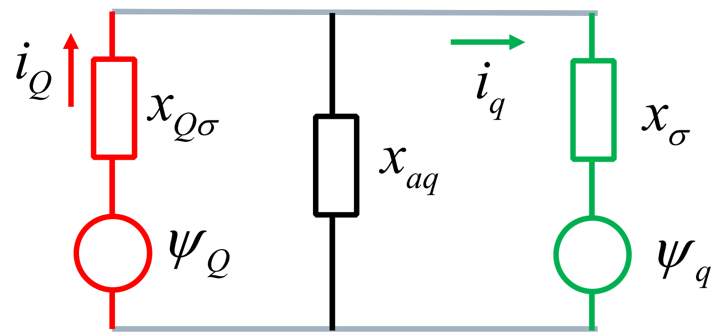
$$\begin{bmatrix} \psi_d \\ \psi_q \\ \psi_0 \\ \psi_f \\ \psi_D \\ \psi_Q \end{bmatrix} = \begin{bmatrix} x_d & 0 & 0 & x_{ad} & x_{ad} & 0 \\ 0 & x_q & 0 & 0 & 0 & x_{aq} \\ 0 & 0 & x_0 & 0 & 0 & 0 \\ x_{ad} & 0 & 0 & x_f & x_{ad} & 0 \\ x_{ad} & 0 & 0 & x_{ad} & x_D & 0 \\ 0 & x_{aq} & 0 & 0 & 0 &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



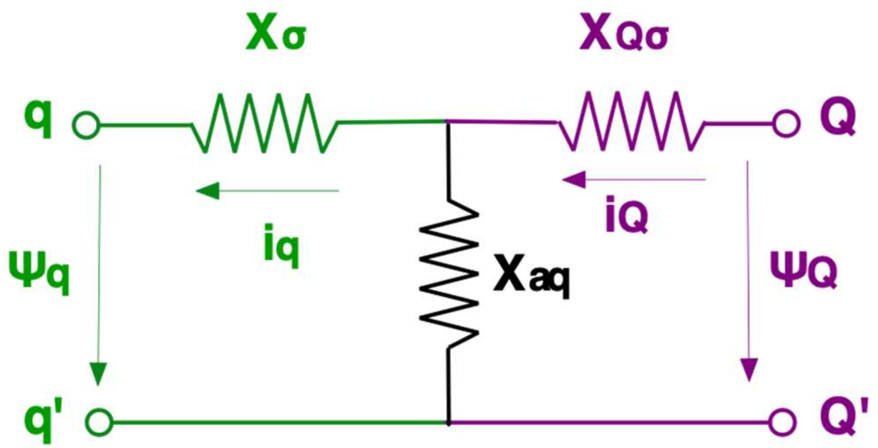
派克变换的应用实例之二——发电机等值电路

- **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**



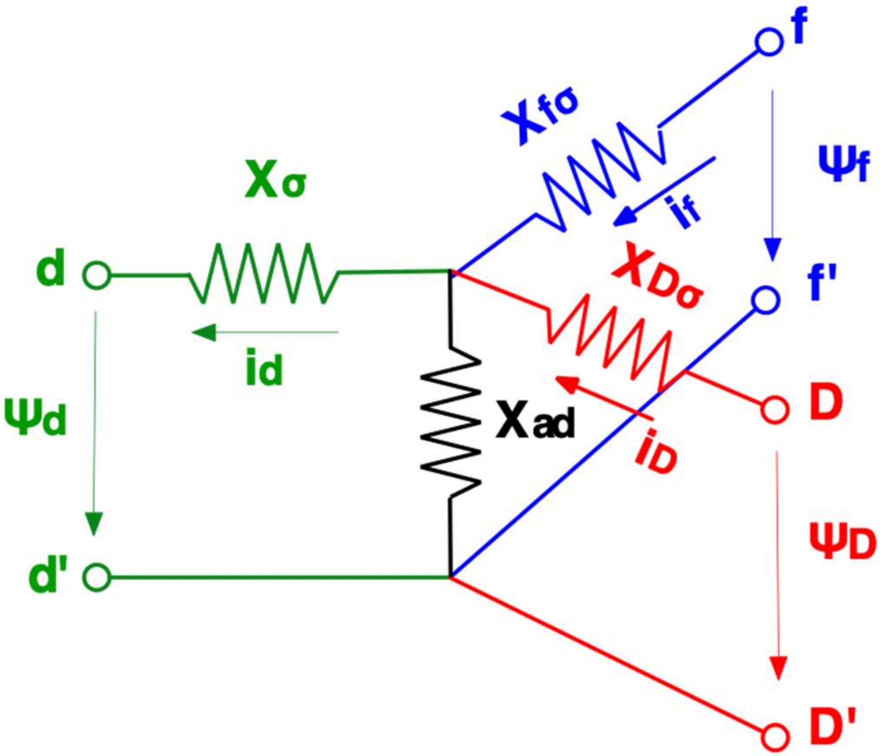
$$x_q = x_\sigma + x_{aq}$$

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

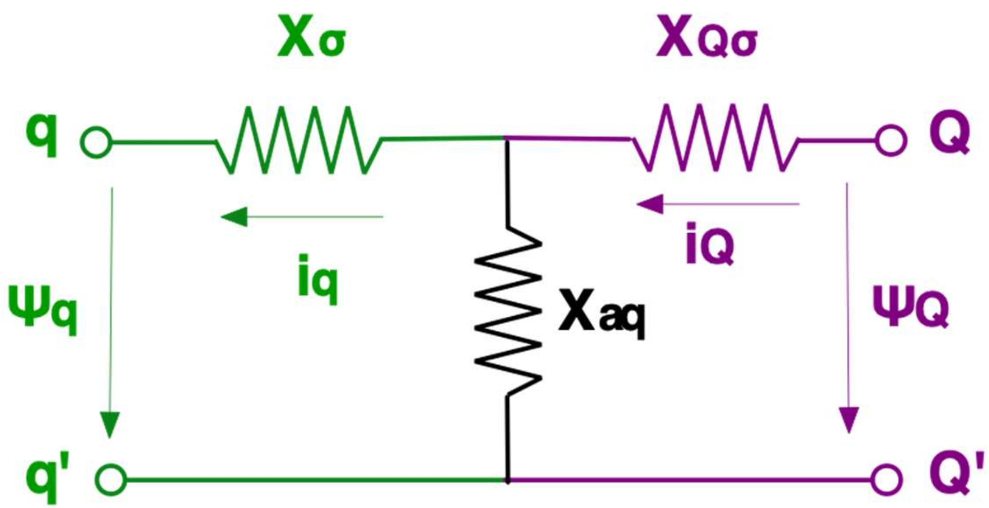
派克变换的应用实例之二——发电机等值电路

- 磁链和电流的关系

- d轴等值电路



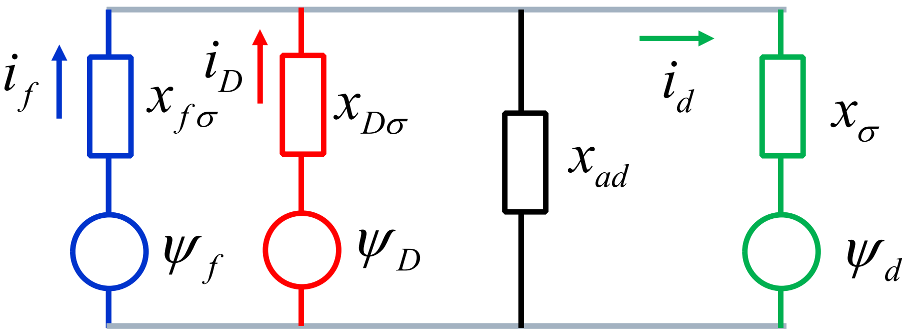
- q轴等值电路



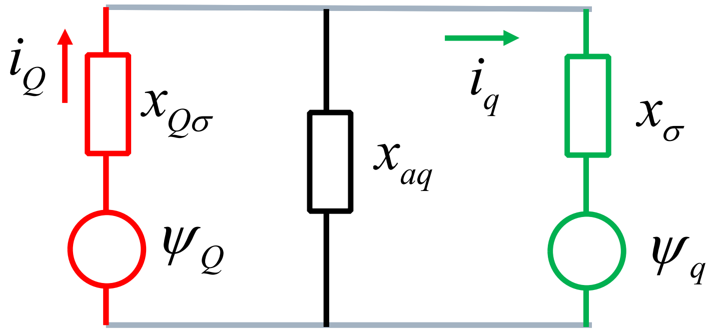
派克变换的应用实例之二——发电机等值电路

- 磁链和电流的关系

- d轴等值电路



- 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；

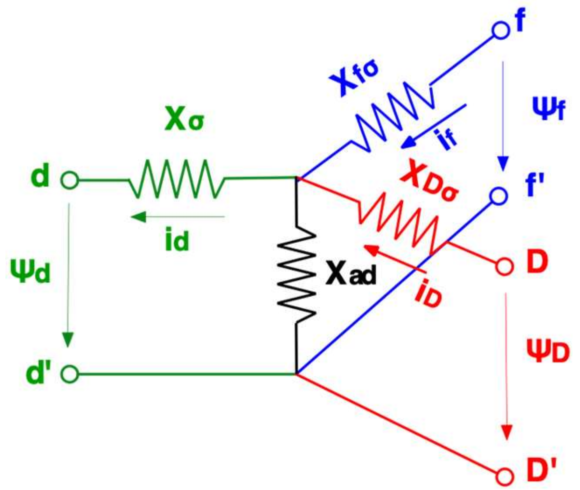
2、电磁暂态过程中，转速维持同步速；

3、忽略定子电阻。

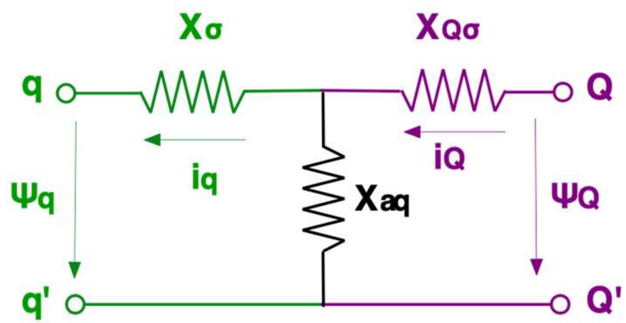
$$u_d = -\psi_q \quad u_q = \psi_d$$

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

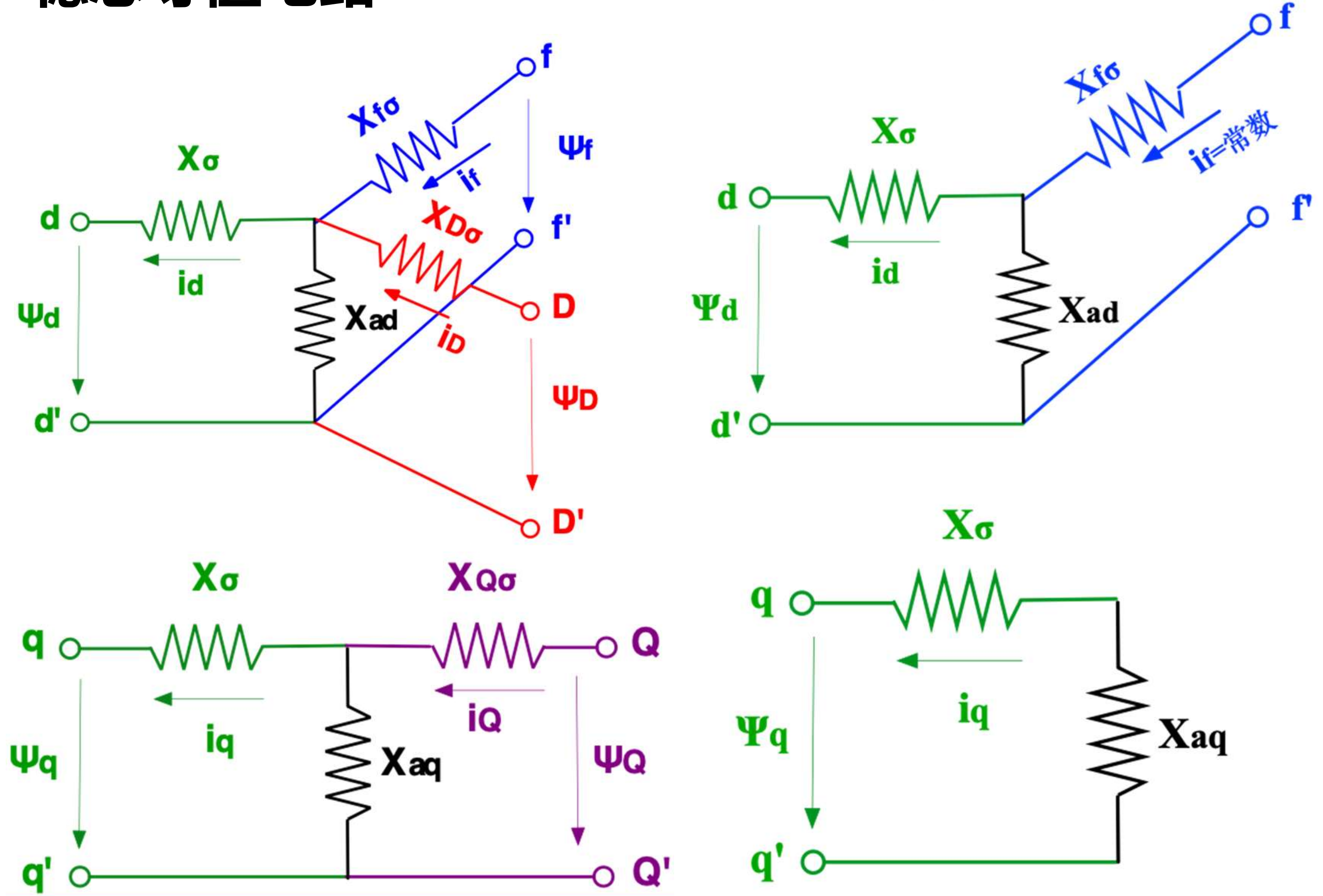


■ q轴磁链和电流的关系



派克变换的应用实例之二——发电机等值电路

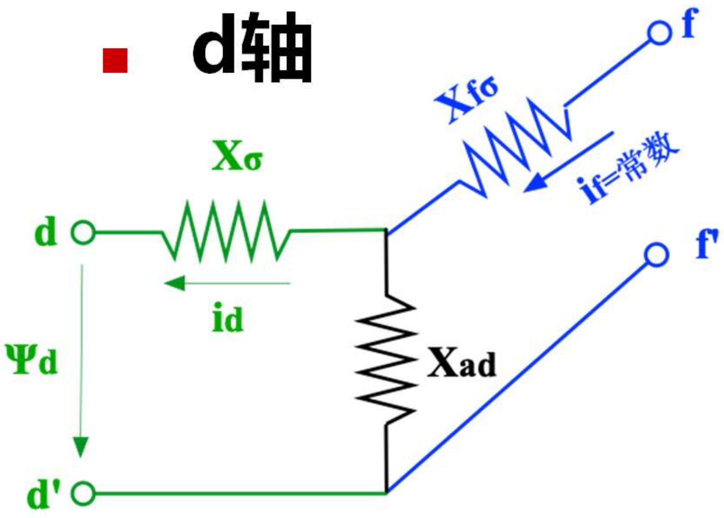
- **稳态等值电路** → $i_D=0$，$i_Q=0$，$i_f=$常数



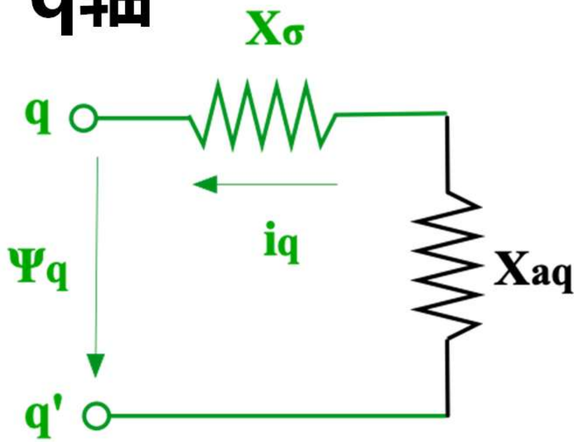
派克变换的应用实例之二——发电机等值电路

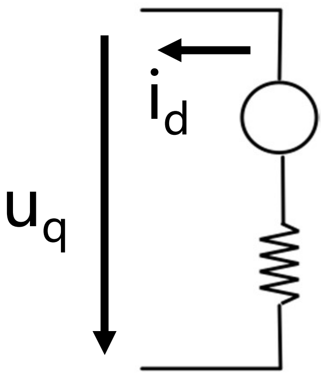
- **稳态等值电路** → $i_D=0$，$i_Q=0$，$i_f=$常数

- **d轴**



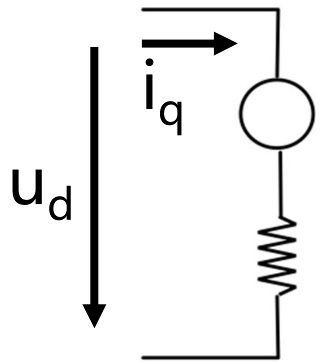
- **q轴**





$$E_q = x_{ad} i_f$$

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



$$E_d = 0$$

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

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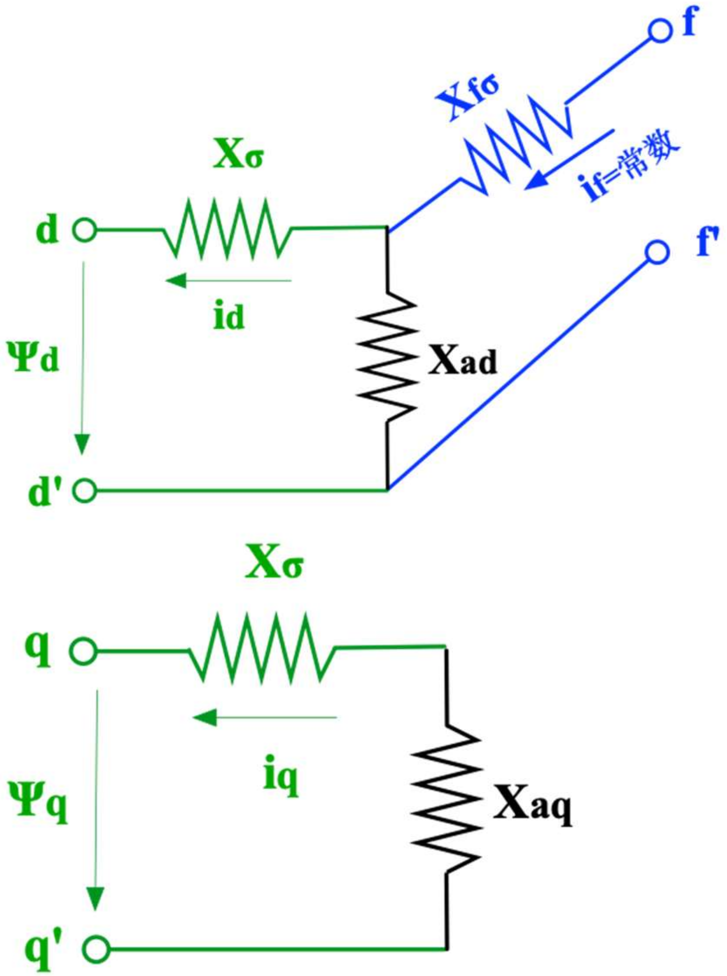
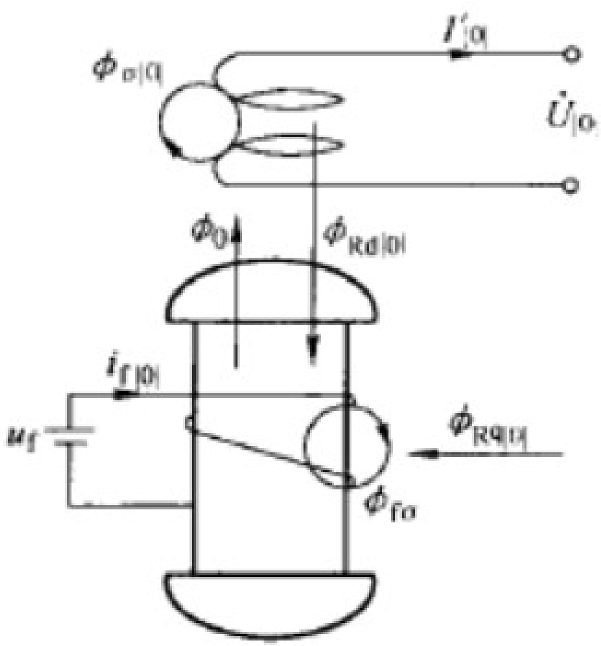
派克变换的应用实例之二——发电机等值电路

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





a)　　P10 图1-8

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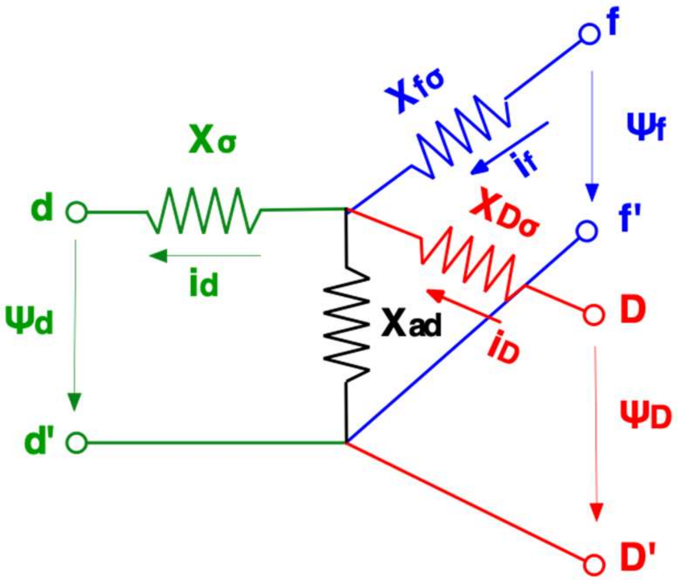
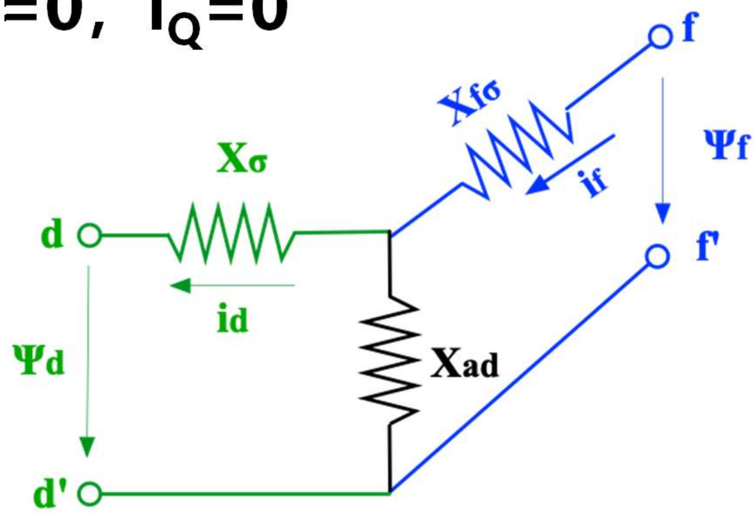
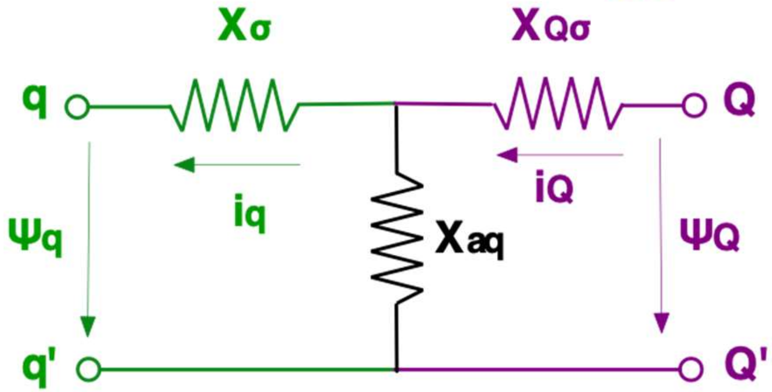
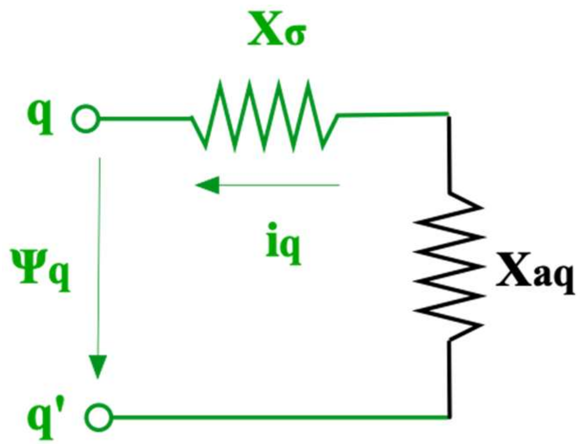
派克变换的应用实例之二—发电机等值电路

- 暂态等值电路 → $i_D=0，i_Q=0$









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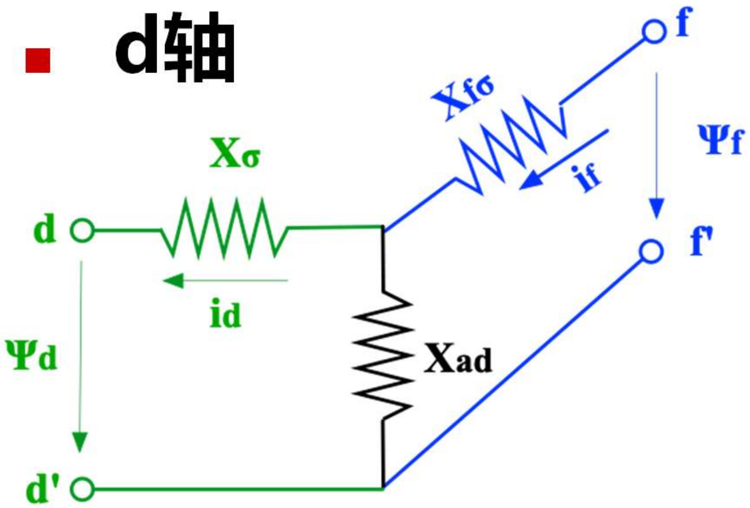
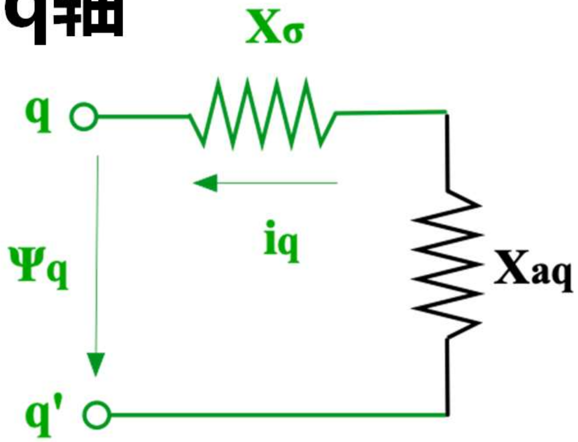
派克变换的应用实例之二—发电机等值电路

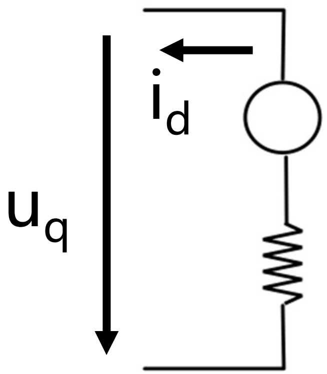
- 暂态等值电路 → $i_D=0$，$i_Q=0$

- d轴



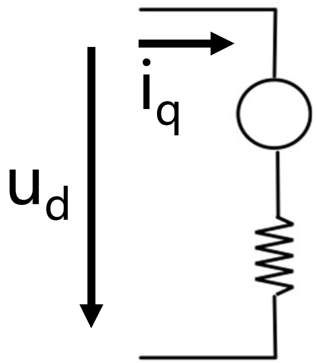
- q轴





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

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

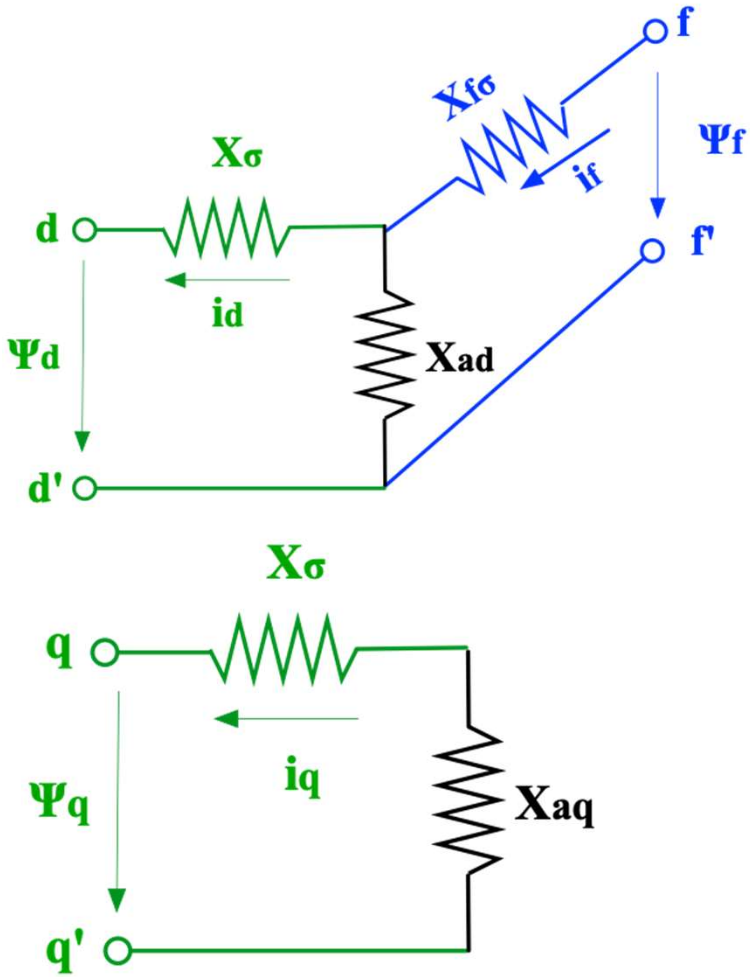


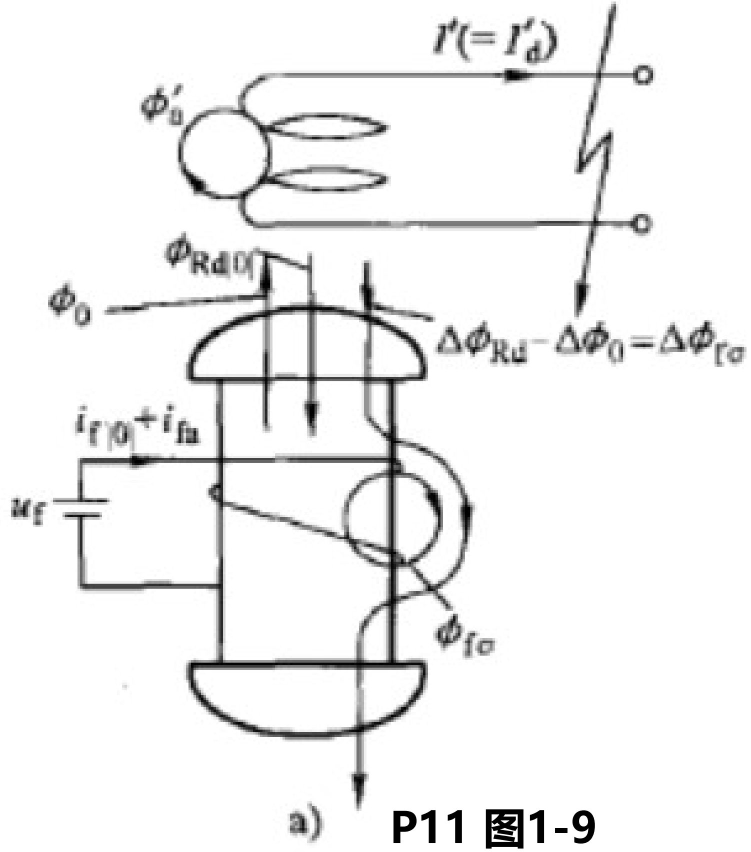
$$E_d = 0$$

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

派克变换的应用实例之二—发电机等值电路

- **暂态等值电路** → $i_D=0，i_Q=0$





P11 图1-9