$$iR + Li' = a\sin\omega t - (b_d\sin\omega t + b_q\cos\omega t)$$

$$i = i_d\sin\omega t + i_q\cos\omega t$$

$$iR + Li' = \cancel{itt}\,[i_d\sin\omega t + i_q\cos\omega t]R$$
$$+L[i_d'\sin\omega t + i_q'\cos\omega t]$$
$$+L[i_d\omega\cos\omega t - i_q\omega\sin\omega t]$$
$$= \sin\omega t[i_d + Li_d' - L\omega i_q] +$$
$$\cos\omega t[i_q + Li_q' + L\omega i_d]$$
$$= \Delta e_d\sin\omega t + \Delta e_q\cos\omega t$$

$$\begin{cases} i_dR + Li_d' - L\omega i_q = \Delta e_d \\ i_qR + Li_q' + L\omega i_d = \Delta e_q \end{cases}$$

$$\begin{cases} Li_d' = L\omega i_q - i_dR + \Delta e_d \\ Li_q' = -L\omega i_d - i_dR + \Delta e_q \end{cases}$$

$$\begin{cases} Li_d' = -i_dR + L\omega i_q + \Delta e_d \\ Li_q' = -i_qR - L\omega i_d + \Delta e_q \end{cases}$$

$$L\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R & L\omega \\ -L\omega & -R \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} \Delta e_d \\ \Delta e_q \end{bmatrix}$$

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & \omega \\ -\omega & -\frac{R}{L} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L}\begin{bmatrix} \Delta e_d \\ \Delta e_q \end{bmatrix}$$

$$\boxed{\dot{x} = Ax + Bu} \qquad u = \begin{bmatrix} \Delta e_d \\ \Delta e_q \end{bmatrix}'$$

$$A = \begin{bmatrix} -\frac{R}{L} & L\omega \\ -\omega & -\frac{R}{L} \end{bmatrix} \qquad B = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \end{bmatrix}$$

$u = \begin{bmatrix} \Delta e_d \\ \Delta e_q \end{bmatrix}$ $\quad x_{ref} = \begin{bmatrix} i_{q\text{-}ref} \\ i_{d\text{-}ref} \end{bmatrix}$

$\dot{x}_e = A x_e + B \Delta u.$

Select Δu. such that $x_e \to 0$.

~~B=~~

现代控制理论: $B = -k x_e$.

$\dot{x}_e = (A - Bk) x_e$.

经典 PI control:

$$\Delta u_d = K_p \Delta I_d + k_I \int_0^t (\Delta I_{de}) dt$$

$$= k_{pd} \Delta I_d + k_{Id} \int_0^t (\Delta I_{d \cdot e}) dt$$

$$\Delta u_q = k_{p\text{-}q} \Delta I_q + k_{I\text{-}q} \int_0^t (\Delta I_{qe}) dt.$$

$$\begin{bmatrix} \Delta u_d \\ \Delta u_q \end{bmatrix} = \begin{bmatrix} K_{pd} & 0 \\ 0 & k_{pi} \end{bmatrix} \begin{bmatrix} I_{d\text{-}e} \\ I_{q\text{-}e} \end{bmatrix} + \begin{bmatrix} K_{id} & 0 \\ 0 & K_{id} \end{bmatrix} \begin{bmatrix} \int I_{de} \\ \int I_{qe} \end{bmatrix}$$

现代控制理论:

$$\frac{d}{dt} \begin{bmatrix} Q_d \\ i_d \\ Q_q \\ i_q \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -\frac{R}{L} & 0 & \omega \\ 0 & 0 & 1 & 0 \\ 0 & -\omega & 0 & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} Q_d \\ i_d \\ Q_q \\ i_q \end{bmatrix} + \underbrace{\begin{bmatrix} 0 & 0 \\ \frac{1}{L} & 0 \\ 0 & 0 \\ 0 & 1/L \end{bmatrix}}_{[B]} \underbrace{\begin{bmatrix} \Delta e_d \\ \Delta e_q \end{bmatrix}}_{u}$$

$B = -k x_e \qquad \dot{x}_e = (A - Bk) \dot{x}_e$

→ use preview LQR control. / <u>LQR control</u>.

如何从 $\Delta e_q / \Delta e_d$ 映射到 SPWM

$$\begin{cases} u_{SMB-d} = \underbrace{\Delta e_d}_{\text{已知}} - \underbrace{e_{AC-d}}_{\text{测量}} \rightarrow \text{电网直轴电压} \\ u_{SMB-q} = \underbrace{\Delta e_q}_{\text{已知}} - \underbrace{e_{AC-q}}_{\text{测量}} \ \text{电网交轴电压} \end{cases}$$

$$\begin{bmatrix} u_{SMB-\alpha} \\ u_{SMB-\beta} \end{bmatrix} = \begin{bmatrix} \cos v & \sin v \\ -\sin v & \cos v \end{bmatrix} \begin{bmatrix} u_{SMB-d} \\ u_{SMB-q} \end{bmatrix} \leftarrow \alpha\beta/dq \ \text{变换}$$

$$\underset{\text{系数}}{PWM} = k \cdot u_{SMB-\alpha}.$$

k 已知 $u_{SMB-\alpha}$ 计算得知，可算得 PWM 调制系数

由 PWM 调制系数 $\rightarrow$ 得 SPWM 波形.

如果是基频控制(?)

$$\frac{PWM}{V_{m-d}} = k \left(u_{SMB-\alpha} - u_{\text{基波}} \right).$$