ECE 529
Utility Applications of Power Electronics
Session 25
How do we keep negative sequence voltages in sync? Is there a current in the PLL output? What are the control loops in sync? Which filter is better for V, Vg, Vb, etc.? Is it not that challenging since 120 Hz is much higher than 60 Hz? What are the things we want to track?
Option 2

Decoupled Double Synch Frame PLL

Positive +
- Negative sequence

For h's transforms

\( i_d^+ \), \( i_q^+ \)
\( i_d^- \), \( i_q^- \)
\( v_d^+ \), \( v_q^+ \)
\( v_d^- \), \( v_q^- \)

Advantage, converter can then control (regulate)

\( i_d^- \), \( i_q^- \)
separately from

\( i_d^+ \), \( i_q^+ \)

Current regulators
- Grid codes or utility specs
  that designate negative
  sequence current response
  to faults

$\Rightarrow$ IEEE Std. 2800

- Fault response
  $\Rightarrow$ $|I_2|$ relative to $|I_1|

  $\Rightarrow$ $\frac{e_2}{I_2}$ relative to Ref
Directional element

→ Supervision

Reverse fault

Forward fault

Forward

| TR |

Block tripping for reverse fault $|I| > \text{Th}$
Negative sequence directional element

Sequence networks

POS

VSC

Z_{is}

NEG

Z_{zs}

Z_{ns}

Zero simulator

mZ_{line1}  (1-m)Z_{line1}

mZ_{line2}  (1-m)Z_{line2}

LL fault

BR

GRIP

In

V_{x}
Decoupled-Double Synchronous Reference Frame PLL

- separate positive and negative sequence synchronous reference frame
- allow independent regulation of positive and negative sequence currents

\[
\begin{align*}
\nu_{dq+1} &= \begin{bmatrix} \nu_{d+1} \\ \nu_{q+1} \end{bmatrix} = [T_{dq+1}] \ast \nu_{\alpha\beta} = V^+ \begin{bmatrix} 1 \\ 0 \end{bmatrix} + V^- \begin{bmatrix} \cos(-2\omega t) \\ \sin(-2\omega t) \end{bmatrix} \\
\nu_{dq-1} &= \begin{bmatrix} \nu_{d-1} \\ \nu_{q-1} \end{bmatrix} = [T_{dq-1}] \ast \nu_{\alpha\beta} = V^- \begin{bmatrix} 1 \\ 0 \end{bmatrix} + V^+ \begin{bmatrix} \cos(2\omega t) \\ \sin(2\omega t) \end{bmatrix}
\end{align*}
\]

\[
[T_{dq+1}] = [T_{dq-1}]^T = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix}
\]

\[
V_\alpha(t) = \frac{2}{3} (V_a(t) - \frac{1}{2} V_b(t) - \frac{1}{2} V_c(t)),
\]

\[
V_\beta(t) = \frac{1}{\sqrt{3}} (V_b(t) - V_c(t)),
\]

Decoupling network to cancel double frequency oscillations

\[
\text{subtract negative double frequency term to subtract}
\]

\[
\text{calculated negative term from measured term.}
\]

PLL output
\[
LFF(s) = \frac{s \omega_f}{s + \omega_f}
\]
\[
\omega_f = \frac{\omega}{2}
\]

ECE 529:
Utility Apps of Power Electronics

Session 24; 2/5
Spring 2023
Time constant - delays magnitude and angle response