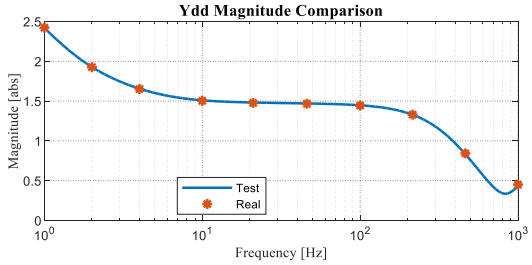
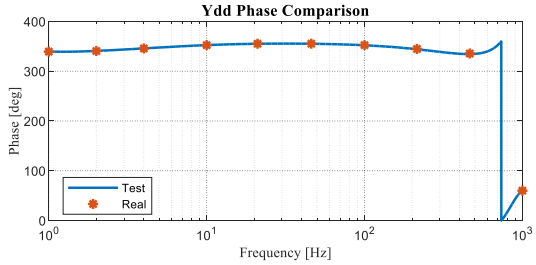
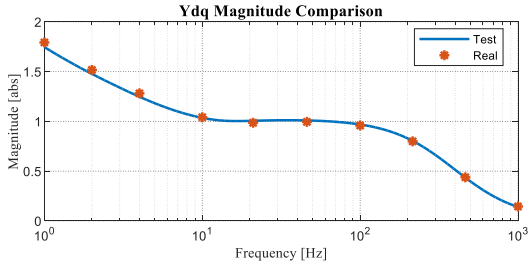
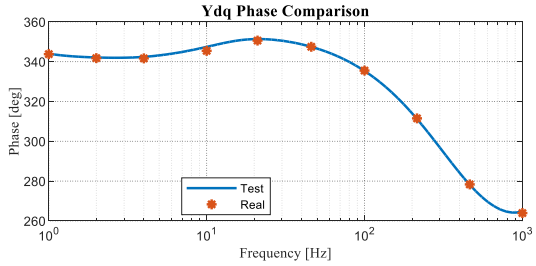
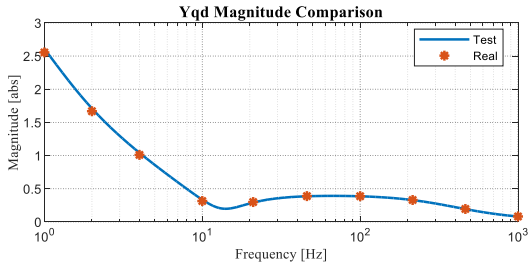
Comparison Result:

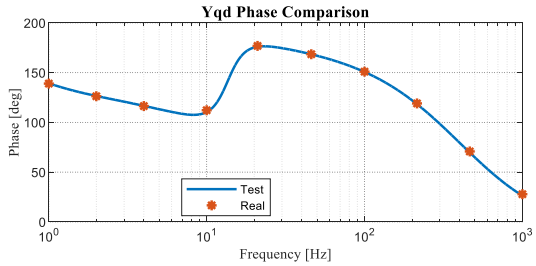


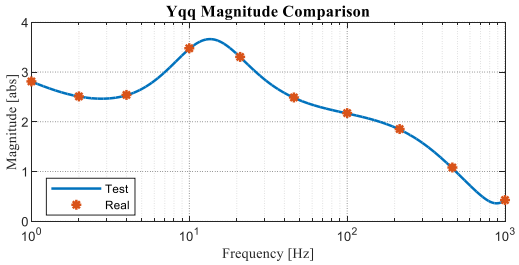


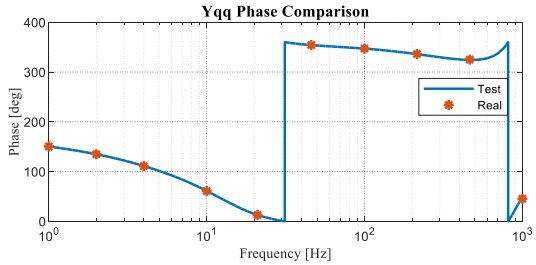












We use the superscript ^{c} to denote the control coordinate, and ^{s} for the system coordinate. The two coordinates will be different during transient states because of the synchronization loops. Subscript $_{c}$ for voltage and current just at the terminal of converters, and $_{o}$ for the output after filters.

Synchronization:

$$\omega = \frac{1}{Js+D}(P_{ref}-P),\ \Delta\delta = G_p(s)\Delta P,\ G_p(s) = -\frac{1}{s(Js+D)}$$

Power calculation:

$$\Delta P = \underbrace{\frac{3}{2}[V_{od}\quad V_{oq}]}_{\mathbf{G}_{iop}}\Delta i^{c}_{odq} + \underbrace{\frac{3}{2}[I_{od}\quad I_{oq}]}_{\mathbf{G}_{uop}}\Delta v^{c}_{odq}$$

$$\Delta\delta = G_p(s)\mathbf{G}_{iop}\Delta i^{c}_{odq} + G_p(s)\mathbf{G}_{uop}\Delta v^{c}_{odq}$$

Axis transformation:

$$\Delta v_{odq}^{c} = \mathbf{I}\Delta v_{odq}^{s} + \underbrace{\begin{bmatrix} V_{oq} \\ -V_{od} \end{bmatrix} G_p \mathbf{G}_{iop}}_{\mathbf{G}_{iovo}} \Delta i_{odq}^{c} + \underbrace{\begin{bmatrix} V_{oq} \\ -V_{od} \end{bmatrix} G_p \mathbf{G}_{uop}}_{\mathbf{G}_{vovo}} \Delta v_{odq}^{c}$$

$$\Rightarrow (\mathbf{I} - \mathbf{G}_{vovo})\Delta v_{odq}^{c} = \mathbf{I}\Delta v_{odq}^{s} + \mathbf{G}_{iovo}\ \Delta i_{odq}^{c} \Rightarrow \Delta v_{cdq}^{c} = \underbrace{(\mathbf{I} - \mathbf{G}_{vovo})^{-1}}_{\mathbf{G}_1}\Delta v_{odq}^{s} + \underbrace{(\mathbf{I} - \mathbf{G}_{vovo})^{-1}\mathbf{G}_{iovo}}_{\mathbf{G}_2}\Delta i_{odq}^{c}$$

$$\Delta i_{odq}^{c} = \mathbf{I}\Delta i_{odq}^{s} + \underbrace{\begin{bmatrix} I_{oq} \\ -I_{od} \end{bmatrix} G_p \mathbf{G}_{iop}}_{\mathbf{G}_{ioio}} \Delta i_{odq}^{c} + \underbrace{\begin{bmatrix} I_{oq} \\ -I_{od} \end{bmatrix} G_p \mathbf{G}_{uop}}_{\mathbf{G}_{voio}} \Delta v_{odq}^{c}$$

$$\Rightarrow (\mathbf{I} - \mathbf{G}_{ioio})\Delta i_{odq}^{c} = \mathbf{I}\Delta i_{odq}^{s} + \mathbf{G}_{voio}\Delta v_{odq}^{c} \Rightarrow \Delta i_{odq}^{c} = \underbrace{(\mathbf{I} - \mathbf{G}_{ioio})^{-1}}_{\mathbf{G}_3}\Delta i_{odq}^{s} + \underbrace{(\mathbf{I} - \mathbf{G}_{ioio})^{-1}\mathbf{G}_{voio}}_{\mathbf{G}_4}\Delta v_{odq}^{c}$$

$$\Delta v_{odq}^{c} = \mathbf{G}_1\Delta v_{odq}^{s} + \mathbf{G}_2\Delta i_{odq}^{c},\ \Delta i_{odq}^{c} = \mathbf{G}_3\Delta i_{odq}^{s} + \mathbf{G}_4\Delta v_{odq}^{c}$$

$$\Rightarrow \Delta v_{odq}^{c} = \mathbf{G}_1\Delta v_{odq}^{s} + \mathbf{G}_2\mathbf{G}_3\Delta i_{odq}^{s} + \mathbf{G}_2\mathbf{G}_4\Delta v_{odq}^{c},$$
$$\Rightarrow \Delta v_{odq}^{c} = \underbrace{(\mathbf{I} - \mathbf{G}_2\mathbf{G}_4)^{-1}\mathbf{G}_1}_{G_{usuc}}\Delta v_{odq}^{s} + \underbrace{(\mathbf{I} - \mathbf{G}_2\mathbf{G}_4)^{-1}\mathbf{G}_2\mathbf{G}_3}_{G_{isuc}}\Delta i_{odq}^{s}$$

$$\Rightarrow \Delta i_{odq}^{c} = \mathbf{G}_3\Delta i_{odq}^{s} + \mathbf{G}_4\mathbf{G}_1\Delta v_{odq}^{s} + \mathbf{G}_4\mathbf{G}_2\Delta i_{odq}^{c},$$
$$\Rightarrow \Delta i_{odq}^{c} = \underbrace{(\mathbf{I} - \mathbf{G}_4\mathbf{G}_2)^{-1}\mathbf{G}_3}_{G_{isic}}\Delta i_{odq}^{s} + \underbrace{(\mathbf{I} - \mathbf{G}_4\mathbf{G}_2)^{-1}\mathbf{G}_4\mathbf{G}_1}_{G_{usic}}\Delta v_{odq}^{s}$$

More axis transformation:

$$\Delta i_{cdq}^{c} = \mathbf{I}\Delta i_{cdq}^{s} + \underbrace{\begin{bmatrix} I_{cq} \\ -I_{cd} \end{bmatrix} G_p \mathbf{G}_{iop}}_{\mathbf{G}_{voic}} \Delta i_{odq}^{c} + \underbrace{\begin{bmatrix} I_{cq} \\ -I_{cd} \end{bmatrix} G_p \mathbf{G}_{uop}}_{\mathbf{G}_{voic}} \Delta v_{odq}^{c}$$

$$\begin{aligned} \Rightarrow \Delta i_{cdq}^{c} &= \mathbf{I}\Delta i_{cdq}^{s} + \mathbf{G}_{ioic}\ (\mathbf{G}_{isic}\Delta i_{odq}^{s} + \mathbf{G}_{usic}\Delta v_{odq}^{s}) + \mathbf{G}_{voic}(\mathbf{G}_{usuc}\Delta v_{odq}^{s} + \mathbf{G}_{isuc}\Delta i_{odq}^{s}) \\ &= \mathbf{I}\Delta i_{cdq}^{s} + \underbrace{(\mathbf{G}_{ioic}\ \mathbf{G}_{isic} + \mathbf{G}_{voic}\mathbf{G}_{isuc})}_{\mathbf{G}_{iscc}}\Delta i_{odq}^{s} + \underbrace{(\mathbf{G}_{ioic}\ \mathbf{G}_{usic} + \mathbf{G}_{voic}\mathbf{G}_{usuc})}_{\mathbf{G}_{uscc}}\Delta v_{odq}^{s} \end{aligned}$$

$$\Delta v_{cdq}^{c} = \mathbf{I}\Delta v_{cdq}^{s} + \underbrace{\begin{bmatrix} V_{cq} \\ -V_{cd} \end{bmatrix} G_p \mathbf{G}_{iop}}_{\mathbf{G}_{iovc}} \Delta i_{odq}^{c} + \underbrace{\begin{bmatrix} V_{cq} \\ -V_{cd} \end{bmatrix} G_p \mathbf{G}_{uop}}_{\mathbf{G}_{vcvc}} \Delta v_{odq}^{c}$$

$$\begin{aligned} \Rightarrow \Delta v_{cdq}^{c} &= \mathbf{I}\Delta v_{cdq}^{s} + \mathbf{G}_{iovc}\ (\mathbf{G}_{isic}\Delta i_{odq}^{s} + \mathbf{G}_{usic}\Delta v_{odq}^{s}) + \mathbf{G}_{vcvc}(\mathbf{G}_{usuc}\Delta v_{odq}^{s} + \mathbf{G}_{isuc}\Delta i_{odq}^{s}) \\ &= \mathbf{I}\Delta v_{cdq}^{s} + \underbrace{(\mathbf{G}_{iovc}\ \mathbf{G}_{isic} + \mathbf{G}_{vcvc}\mathbf{G}_{isuc})}_{\mathbf{G}_{isvcc}}\Delta i_{odq}^{s} + \underbrace{(\mathbf{G}_{iovc}\ \mathbf{G}_{usic} + \mathbf{G}_{vcvc}\mathbf{G}_{usuc})}_{\mathbf{G}_{usvcc}}\Delta v_{odq}^{s} \end{aligned}$$

Reactive power control:

$$v_{d,ref}^{c} = v_0 - \frac{1}{D_q}(Q - Q_{ref}),\ \Delta v_{d,ref}^{c} = G_q(s)\Delta Q,\ \ G_q(s) = -\frac{1}{D_q}$$

$$\Delta Q = \underbrace{\frac{3}{2}[V_{oq}\ \ -V_{od}]}_{\mathbf{G}_{ioq}}\Delta i_{odq}^{c} + \underbrace{\frac{3}{2}[-I_{oq}\ \ I_{od}]}_{\mathbf{G}_{uoq}}\Delta v_{odq}^{c}$$

$$\begin{aligned} \Delta v_{d,ref}^{c} &= \underbrace{G_q(s)\mathbf{G}_{ioq}}_{\mathbf{G}_{qioq}}\Delta i_{odq}^{c} + \underbrace{G_q(s)\mathbf{G}_{uoq}}_{\mathbf{G}_{quoq}}\Delta v_{odq}^{c} \\ &= \mathbf{G}_{qioq}(\mathbf{G}_{isic}\Delta i_{odq}^{s} + \mathbf{G}_{usic}\Delta v_{odq}^{s}) + \mathbf{G}_{quoq}(\mathbf{G}_{usuc}\Delta v_{odq}^{s} + \mathbf{G}_{isuc}\Delta i_{odq}^{s}) \\ &= \underbrace{(\mathbf{G}_{qioq}\mathbf{G}_{usic} + \mathbf{G}_{quoq}\mathbf{G}_{usuc})}_{\mathbf{G}_{11}}\Delta v_{odq}^{s} + \underbrace{(\mathbf{G}_{qioq}\mathbf{G}_{isic} + \mathbf{G}_{quoq}\mathbf{G}_{isuc})}_{\mathbf{G}_{12}}\Delta i_{odq}^{s} \end{aligned}$$

Voltage control loop:

$$i_{dq,ref}^{c} = \begin{bmatrix} \mathrm{PI_{VC}} \cdot (v_{d,ref}^{c} - v_{od}^{c}) \\ \mathrm{PI_{VC}} \cdot (v_{q,ref}^{c} - v_{oq}^{c}) \end{bmatrix} \Rightarrow \Delta i_{dq,ref}^{c} = \begin{bmatrix} \mathrm{PI_{VC}} \cdot (\Delta v_{d,ref}^{c} - \Delta v_{od}^{c}) \\ \mathrm{PI_{VC}} \cdot (-\Delta v_{oq}^{c}) \end{bmatrix}$$

$$\begin{aligned} \Rightarrow \Delta i_{dq,ref}^{c} &= \begin{bmatrix} \mathrm{PI_{VC}} \cdot (\mathbf{G}_{11}\Delta v_{odq}^{s} + \mathbf{G}_{12}\Delta i_{odq}^{s}) \\ 0 \end{bmatrix} - \begin{bmatrix} \mathrm{PI_{VC}} & 0 \\ 0 & \mathrm{PI_{VC}} \end{bmatrix}\Delta v_{odq}^{c} \\ &= \begin{bmatrix} \mathrm{PI_{VC}} \cdot \mathbf{G}_{11} \\ 0 \quad 0 \end{bmatrix}\Delta v_{odq}^{s} + \begin{bmatrix} \mathrm{PI_{VC}} \cdot \mathbf{G}_{12} \\ 0 \quad 0 \end{bmatrix}\Delta i_{odq}^{s} - \begin{bmatrix} \mathrm{PI_{VC}} & 0 \\ 0 & \mathrm{PI_{VC}} \end{bmatrix}\mathbf{G}_{usuc}\Delta v_{odq}^{s} - \begin{bmatrix} \mathrm{PI_{VC}} & 0 \\ 0 & \mathrm{PI_{VC}} \end{bmatrix}\mathbf{G}_{isuc}\Delta i_{odq}^{s} \\ &= \underbrace{\left(\begin{bmatrix} \mathrm{PI_{VC}} \cdot \mathbf{G}_{11} \\ 0 \quad 0 \end{bmatrix} - \begin{bmatrix} \mathrm{PI_{VC}} & 0 \\ 0 & \mathrm{PI_{VC}} \end{bmatrix}\mathbf{G}_{usuc}\right)}_{\mathbf{H}_1}\Delta v_{odq}^{s} + \underbrace{\left(\begin{bmatrix} \mathrm{PI_{VC}} \cdot \mathbf{G}_{12} \\ 0 \quad 0 \end{bmatrix} - \begin{bmatrix} \mathrm{PI_{VC}} & 0 \\ 0 & \mathrm{PI_{VC}} \end{bmatrix}\mathbf{G}_{isuc}\right)}_{\mathbf{H}_2}\Delta i_{odq}^{s} \end{aligned}$$

Current control loop:

$$v_{cdq}^{c}=\begin{bmatrix}\mathrm{PI}_{\mathrm{CC}}(s) & 0\\ 0 & \mathrm{PI}_{\mathrm{CC}}(s)\end{bmatrix}\begin{bmatrix}i_{d,ref}^{c}-i_{cd}^{c}\\ i_{q,ref}^{c}-i_{cq}^{c}\end{bmatrix}+\begin{bmatrix}v_{od}^{c}\\ v_{oq}^{c}\end{bmatrix}$$

$$\Rightarrow \Delta v_{cdq}^{c}=\mathbf{PI}_{\mathrm{CC}}\cdot\Delta i_{dq,ref}^{c}-\mathbf{PI}_{\mathrm{CC}}\cdot\Delta i_{cdq}^{c}+\Delta v_{odq}^{c}$$

$$=\mathbf{PI}_{\mathrm{CC}}\cdot(\mathbf{H}_1\Delta v_{odq}^{s}+\mathbf{H}_2\Delta i_{odq}^{s})-\mathbf{PI}_{\mathrm{CC}}\cdot(\mathbf{I}\Delta i_{cdq}^{s}+\mathbf{G}_{isicc}\Delta i_{odq}^{s}+\mathbf{G}_{usicc}\Delta v_{odq}^{s})+\ \mathbf{G}_{usuc}\Delta v_{odq}^{s}+\mathbf{G}_{isuc}\Delta i_{odq}^{s}$$

$$=\underbrace{(\mathbf{PI}_{\mathrm{CC}}\cdot\mathbf{H}_1-\mathbf{PI}_{\mathrm{CC}}\cdot\mathbf{G}_{usicc}+\mathbf{G}_{usuc})}_{\tilde{\mathbf{H}}_{11}}\Delta v_{odq}^{s}+\underbrace{(\mathbf{PI}_{\mathrm{CC}}\cdot\mathbf{H}_2-\mathbf{PI}_{\mathrm{CC}}\cdot\mathbf{G}_{isicc}+\mathbf{G}_{isuc})}_{\tilde{\mathbf{H}}_{12}}\Delta i_{odq}^{s}-\mathbf{PI}_{\mathrm{CC}}\cdot\Delta i_{cdq}^{s}$$

$$\Delta v_{cdq}^{c}=\mathbf{I}\Delta v_{cdq}^{s}+\mathbf{G}_{isvcc}\Delta i_{odq}^{s}+\mathbf{G}_{vsvcc}\Delta v_{odq}^{s}=\mathbf{H}_{11}\Delta v_{odq}^{s}+\mathbf{H}_{12}\Delta i_{odq}^{s}-\mathbf{PI}_{\mathrm{CC}}\cdot\Delta i_{cdq}^{s}$$

$$(\mathbf{H}_{11}-\mathbf{G}_{vsvcc})\Delta v_{odq}^{s}+(\mathbf{H}_{12}-\mathbf{G}_{isvcc})\Delta i_{odq}^{s}-\mathbf{PI}_{\mathrm{CC}}\cdot\Delta i_{cdq}^{s}-\mathbf{I}\Delta v_{cdq}^{s}=0$$

Filter:

$$\Delta v_{odq}^{s}=\Delta v_{cdq}^{s}-\mathbf{G}_{RLf}\Delta i_{cdq}^{s},\ \Delta i_{cdq}^{s}-\Delta i_{odq}^{s}=\mathbf{C}\Delta v_{odq}^{s}$$
$$\Delta v_{cdq}^{s}=\Delta v_{odq}^{s}+\mathbf{G}_{RLf}\Delta i_{cdq}^{s},\ \Delta i_{cdq}^{s}=\Delta i_{odq}^{s}+\mathbf{C}\Delta v_{odq}^{s}$$
$$\Delta v_{cdq}^{s}=\Delta v_{odq}^{s}+\mathbf{G}_{RLf}(\Delta i_{odq}^{s}+\mathbf{C}\Delta v_{odq}^{s})=(\mathbf{I}+\mathbf{G}_{RLf}\mathbf{C})\Delta v_{odq}^{s}+\mathbf{G}_{RLf}\Delta i_{odq}^{s}$$

Combine:

$$(\mathbf{H}_{11}-\mathbf{G}_{vsvcc})\Delta v_{odq}^{s}+(\mathbf{H}_{12}-\mathbf{G}_{isvcc})\Delta i_{odq}^{s}-\mathbf{PI}_{\mathrm{CC}}\cdot(\Delta i_{odq}^{s}+\mathbf{C}\Delta v_{odq}^{s})-((\mathbf{I}+\mathbf{G}_{RLf}\mathbf{C})\Delta v_{odq}^{s}+\mathbf{G}_{RLf}\Delta i_{odq}^{s})=0$$
$$(\mathbf{H}_{11}-\mathbf{G}_{vsvcc}-\mathbf{PI}_{\mathrm{CC}}\cdot\mathbf{C}-(\mathbf{I}+\mathbf{G}_{RLf}\mathbf{C}))\Delta v_{odq}^{s}+(\mathbf{H}_{12}-\mathbf{G}_{isvcc}-\mathbf{PI}_{\mathrm{CC}}-\mathbf{G}_{RLf})\Delta i_{odq}^{s}=0$$

Global Axis transformation is omitted for brevity, and please refer to m files.