

Modell alapú prediktív szabályozás mikrogridek tranziens stabilitásának eléréséhez

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Tartalom

- KIF mikrogridek
- Modell alapú prediktív szabályozás
- Szinkronkonverter
- Modell alapú prediktív szabályozás szinkronkonverterrel

KIF mikrogridek

- Mikrogrid
 - Képes a hálózathoz csatlakozva és attól függetlenül működni
 - Tartalmaz lokális energia termelő és/vagy tároló egységeket
- Jelentősen kisebb inercia, gyorsabb folyamatok
- Szigetüzemben nehezen értelmezhető FCR/FRR/RR
- Nem alkalmazható a Pf/QU szeparáció

Modell alapú prediktív szabályozás (MPC)

$$X_{k+1} = AX_k + BU_k$$

$$Y_k = CX_k + DU_k$$

$$X_{k+2} = AX_{k+1} + BU_{k+1}$$

$$X_{k+2} = A(AX_k + BU_k) + BU_{k+1}$$

$$X_{k+2} = A^2X_k + ABU_k + BU_{k+1}$$

$$X_{k+3} = A^3X_k + A^2BU_k + ABU_{k+1} + BU_{k+2}$$

$$X_{k+4} = A^4X_k + A^3BU_k + A^2BU_{k+1} + ABU_{k+2} + BU_{k+3}$$

...

$$\begin{bmatrix} X_{k+1} \\ X_{k+2} \\ X_{k+3} \\ \dots \\ X_{k+Hp+1} \end{bmatrix} = \begin{bmatrix} A \\ A^2 \\ A^3 \\ \dots \\ A^{Hp} \end{bmatrix} X_k + \begin{bmatrix} B & 0 & 0 & 0 & \dots & 0 \\ AB & B & 0 & 0 & \dots & 0 \\ A^2B & AB & B & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \end{bmatrix} \begin{bmatrix} U_k \\ U_{k+1} \\ U_{k+2} \\ \dots \\ U_{k+Hu-1} \end{bmatrix}$$

$$X = X_{free} + \Omega U$$

Modell alapú prediktív szabályozás (MPC)

$$X = X_{free} + \Omega U \quad \min \left\{ (x - x_{ref})^T * Q * (x - x_{ref}) \right\}$$

$$X = Z(X_{free} + \Omega U)$$

$$J_I = (Z(x_{free} + \Omega U) - x_{ref})^T * Q * (Z(x_{free} + \Omega U) - x_{ref})$$

$$J_I = (x_{free}^T Z^T + U^T \Omega^T Z^T - x_{ref}^T) * Q * (Zx_{free} + Z\Omega U - x_{ref})$$

$$J_I = x_{free}^T Z^T Q Z x_{free} + x_{free}^T Z^T Q Z \Omega U - x_{free}^T Z^T Q y_{ref} + U^T \Omega^T Z^T Q Z x_{free} + \\ + U^T \Omega^T Z^T Q Z \Omega U - U^T \Omega^T Z^T Q x_{ref} - x_{ref}^T Q Z x_{free} - x_{ref}^T Q Z \Omega U + x_{ref}^T Q y_{ref}$$

$$\left. \begin{aligned} G_I &= x_{free}^T Z^T Q Z \Omega + \Omega Z^T Q Z x_{free} - \Omega Z^T Q x_{ref} - x_{ref}^T Q Z \Omega \\ H_I &= \Omega Z^T Q Z \Omega \end{aligned} \right\} \rightarrow \text{solver}$$

Modell alapú prediktív szabályozás (MPC)

$$AU \leq b$$

$$J_I = (y - y_{ref})^T * Q * (x - x_{ref})$$

$$X_{free} + \Omega U \leq X_{max}$$

$$\Omega U \leq X_{max} - X_{free}$$

$$\underbrace{Z\Omega U}_A \leq \underbrace{Z(X_{max} - X_{free})}_b$$

- Szabályozásnak van költsége

$$J_{II} = J_I + U^T * S * U$$

$$G_{II} = G_I$$

$$H_{II} = H_I + S$$

- Szabályozás változásának is lehet költsége

$$J_{III} = J_{II} + \Delta U^T * S * \Delta U$$

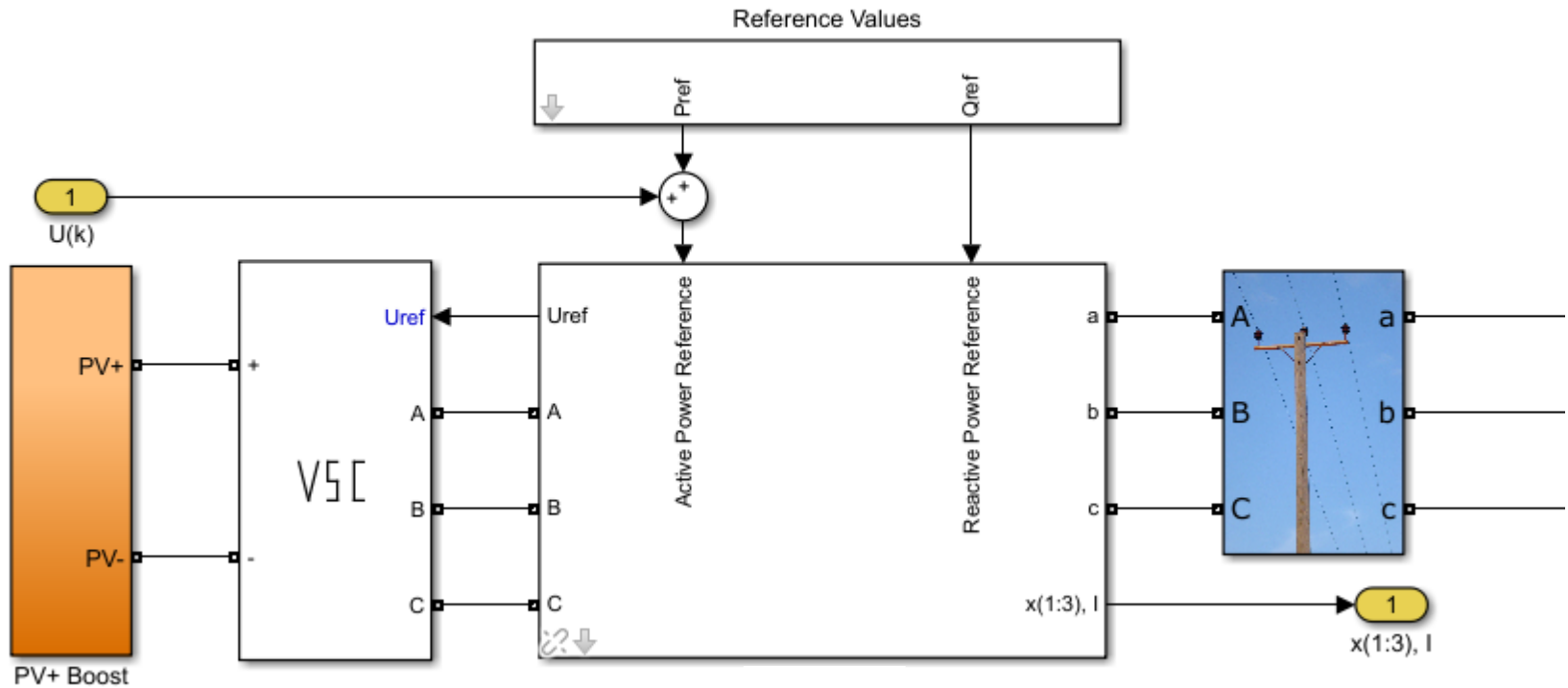
$$\Delta U = \left(\begin{bmatrix} -1 & -0 & -0 & -0 & -0 & \dots & -0 & -0 \\ -1 & -1 & -0 & -0 & -0 & \dots & -0 & -0 \\ -0 & -1 & -1 & -0 & -0 & \dots & -0 & -0 \\ -0 & -0 & -1 & -1 & -0 & \dots & -0 & -0 \\ \dots & -0 & -0 & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & -0 & -0 & \dots & -1 & -1 \end{bmatrix} * U + \begin{bmatrix} -U_{ref} \\ 0 \\ 0 \\ 0 \\ \dots \\ 0 \end{bmatrix} \right)^T * R = MS1 * U + MS2$$

$$J_{III} = J_{II} + U^T M_{s1}^T R M_{s1} U + U^T M_{s1}^T R M_{s2} + M_{s2}^T R M_{s1} U + M_{s2}^T R M_{s2}$$

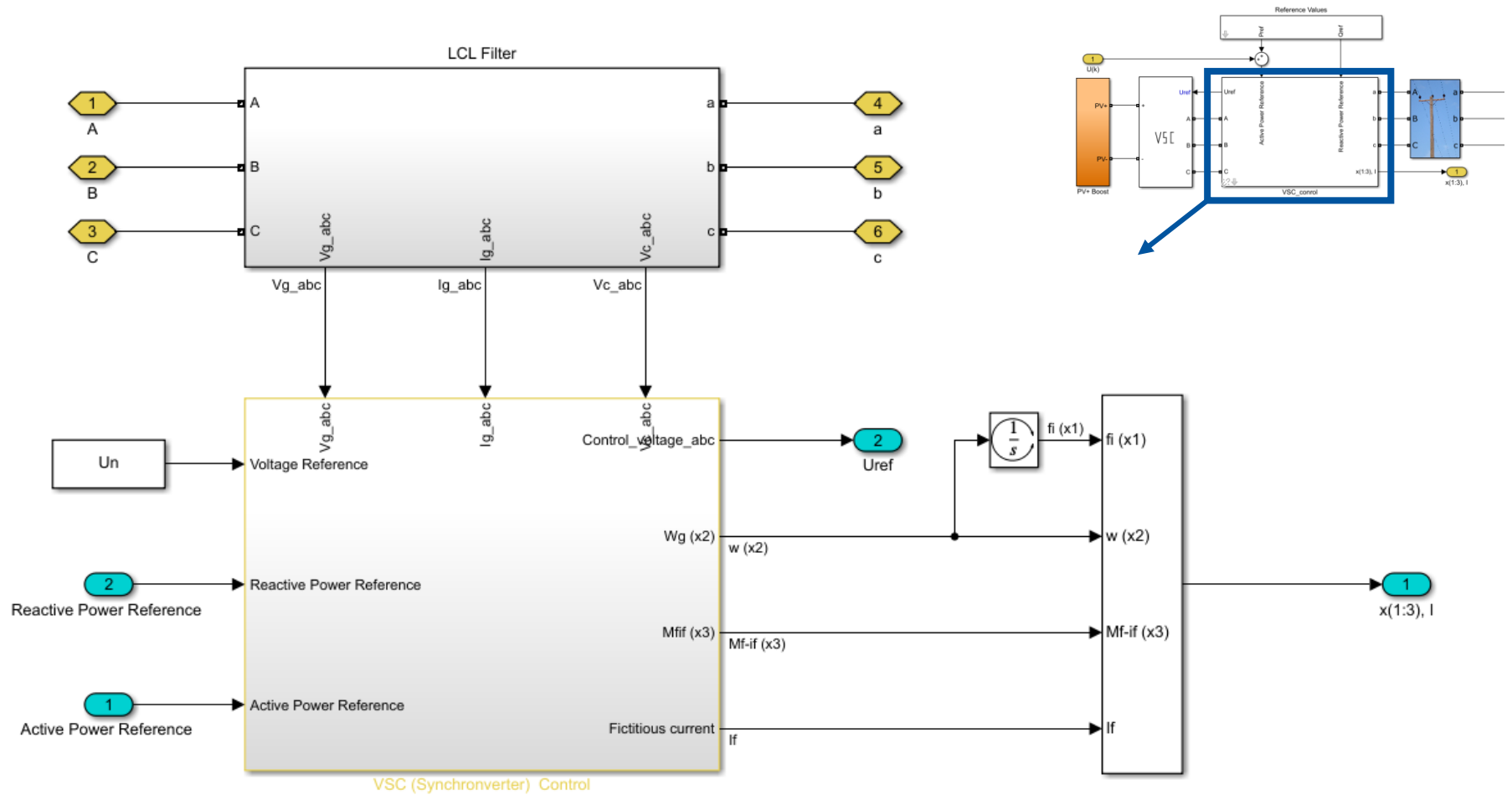
$$G_I \# \bar{x}_{free}^T Q Z \Omega + \Omega Z^T Q x_{ref} - x_{ref}^T Q Z \Omega$$

$$H_I \# \bar{\Omega} Z^T Q Z \Omega M_{s1}^T R M_{s1}$$

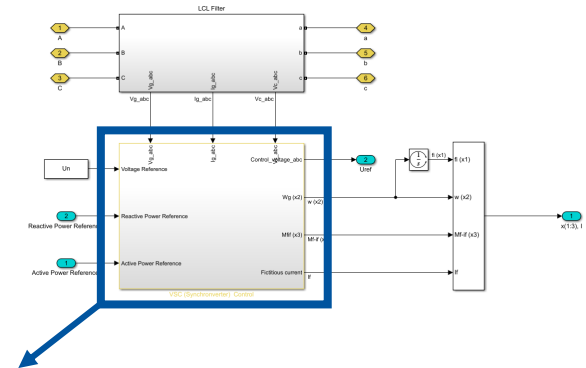
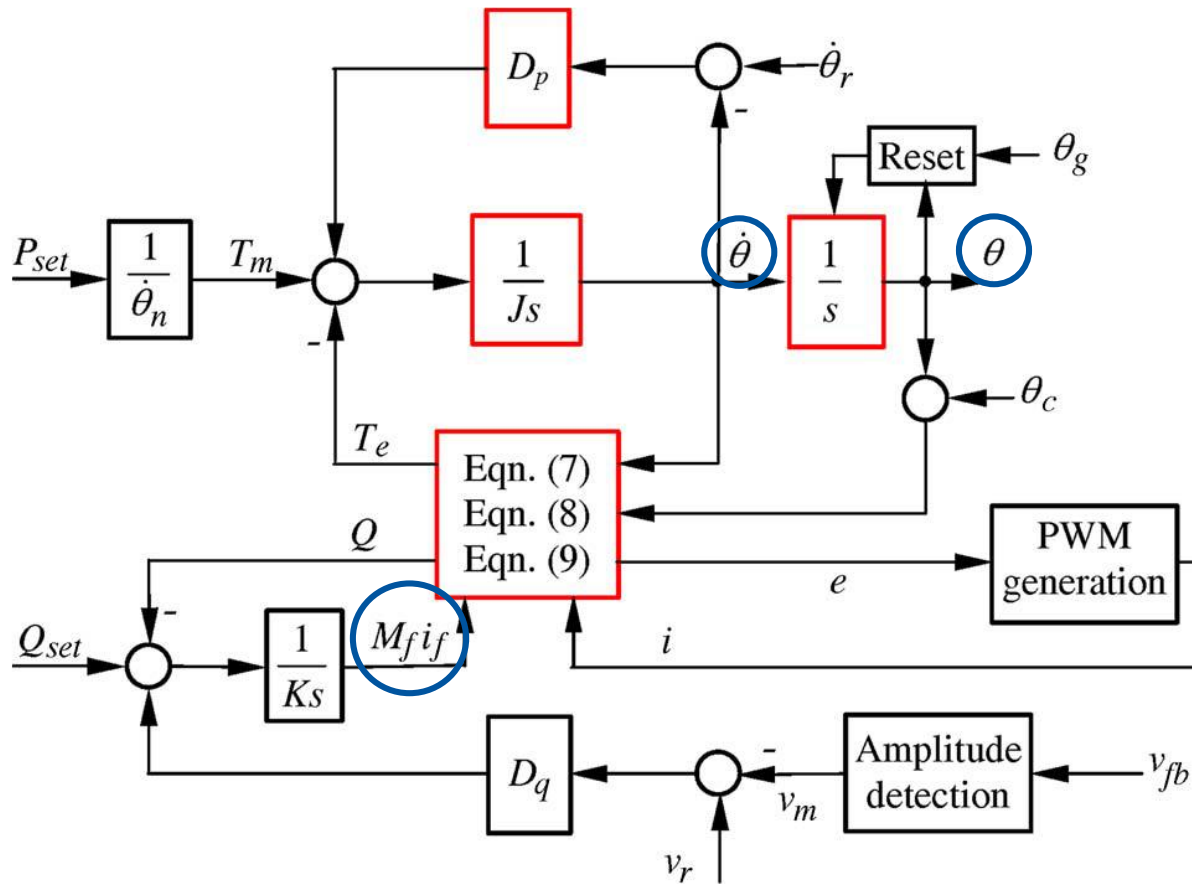
Szinkronkonverter



Szinkronkonverter



Szinkronkonverter

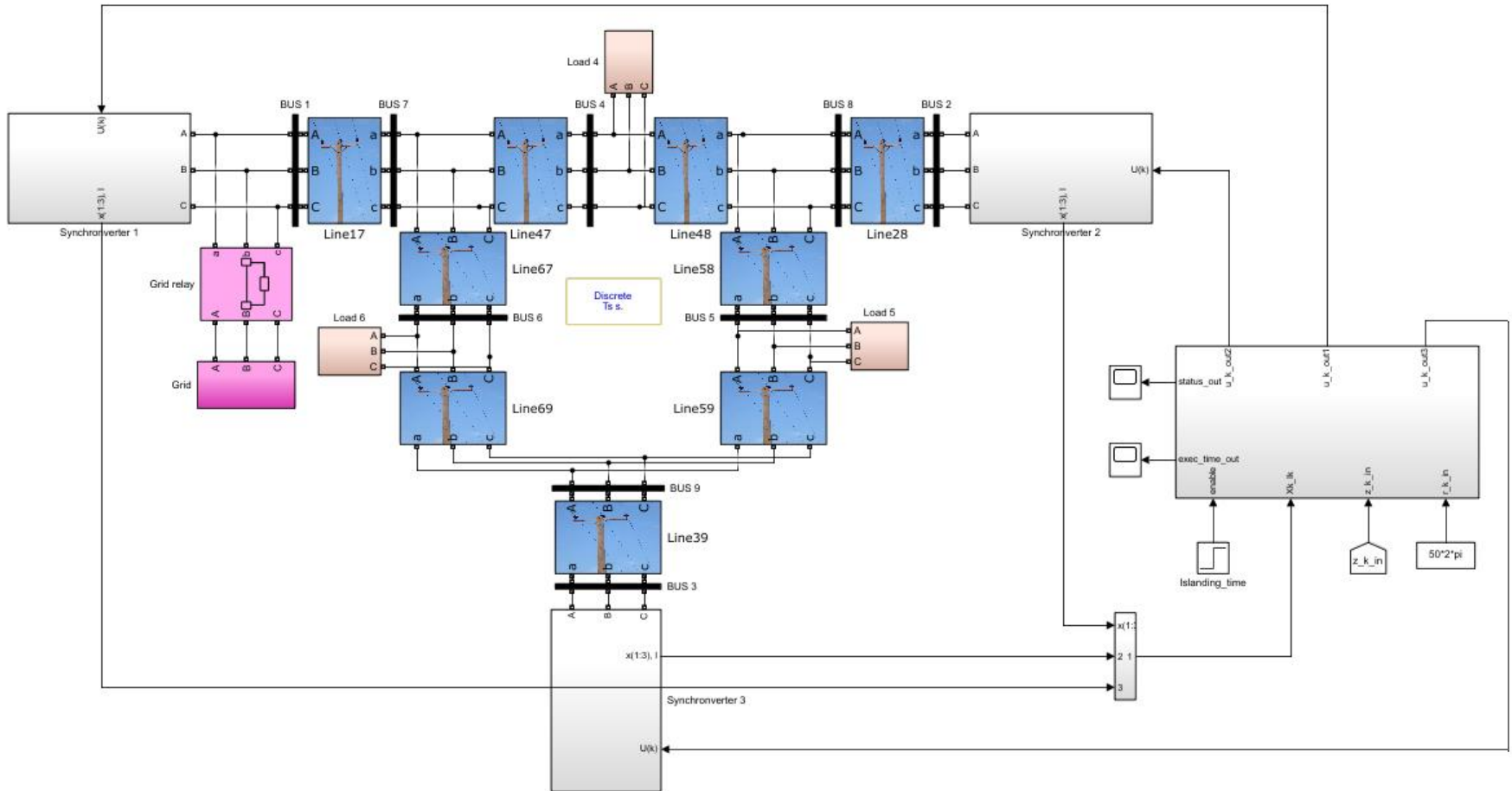


From/to the power part

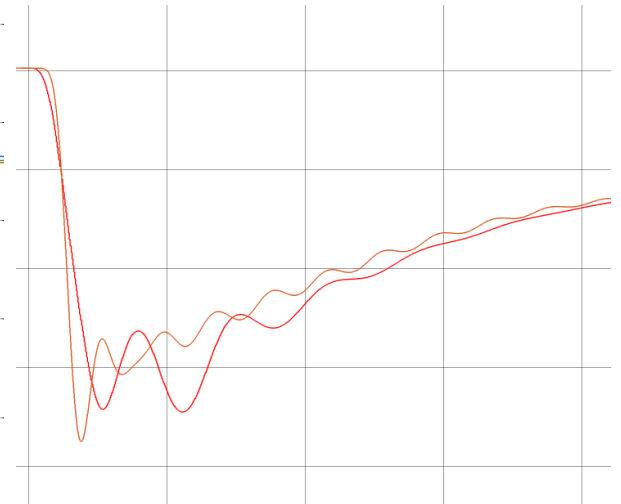
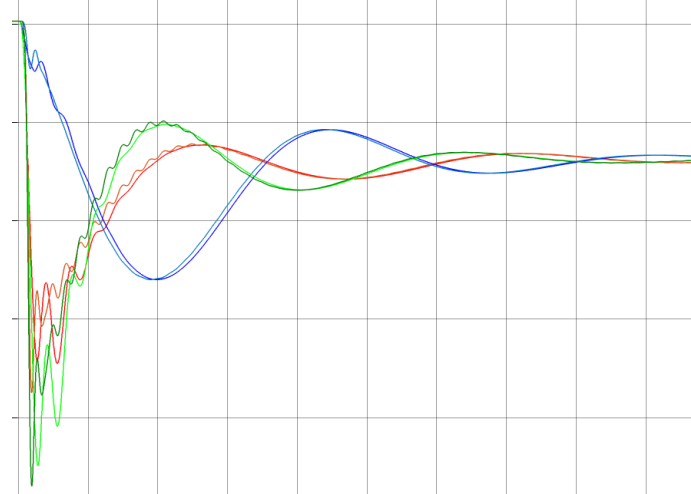
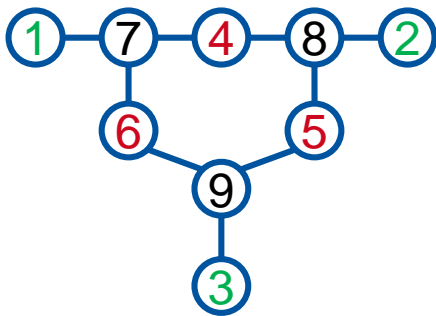
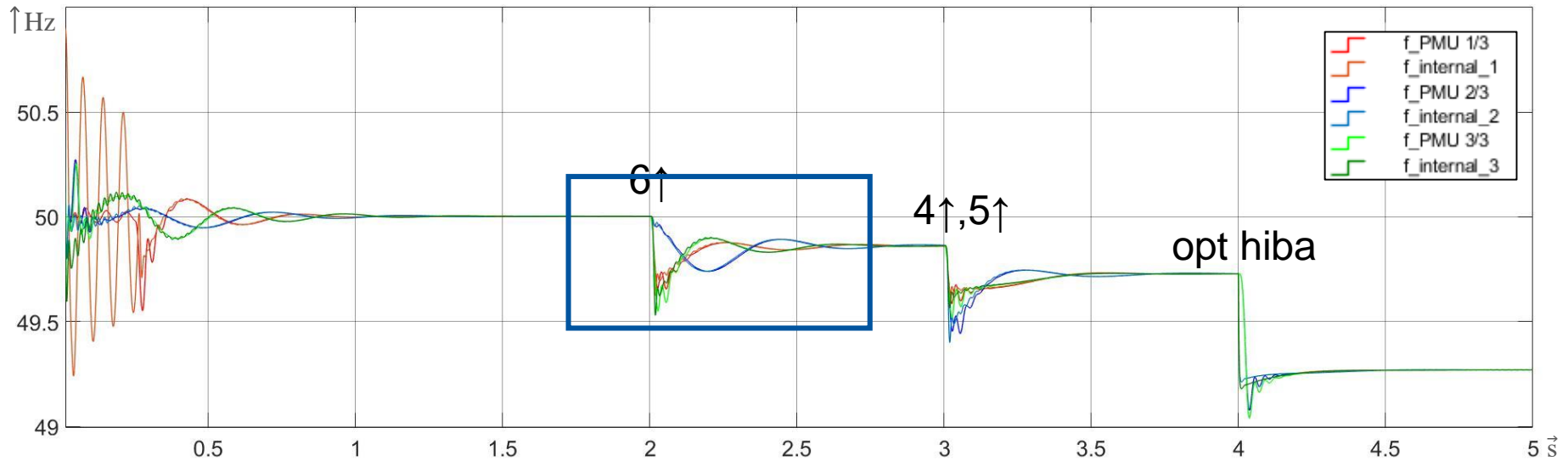
$$\begin{aligned}
 e &= \dot{\theta} M_f i_f \sin \theta \\
 &\quad X_1(k) \\
 &\quad X_2(k) \\
 Q &= -\dot{\theta} M_f i_f \cos \theta \\
 &\quad X_3(k) \\
 &\quad X_1(k+1) \\
 T_e \bar{X} &= M_f i_f \sin \theta \\
 &\quad X_2(k+1) \\
 &\quad \dots \\
 &\quad X_1(k+H_p) \\
 &\quad X_2(k+H_p) \\
 \begin{bmatrix} \theta \\ \dot{\theta} \\ M_f i_f \end{bmatrix} &\quad X_3(k+H_p)
 \end{aligned}$$

Source: Qing-Chang Zhong, George Weiss:
 Synchronverters: Inverters That Mimic Synchronous Generators
 IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 58, NO. 4, APRIL 2011

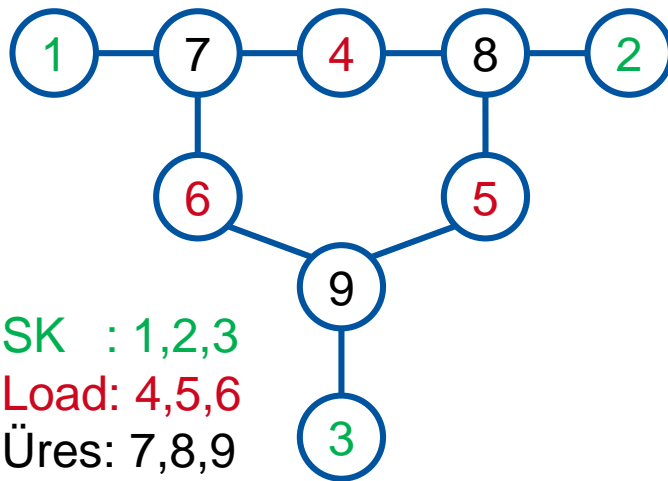
Szinkronkonverter



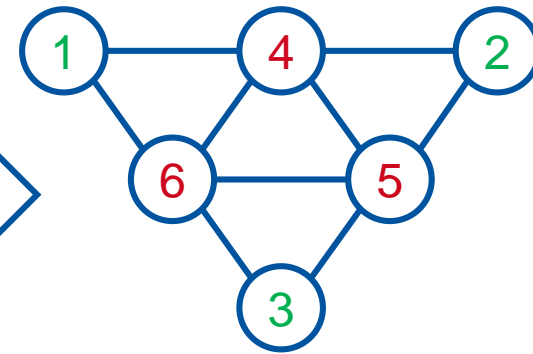
Szinkronkonverter



Modell alapú prediktív szabályozás szinkronkonverterrel



Kron redukció



Frekvenciaosztó

$$w_{456} = 1 + D(w_{123} - 1)$$

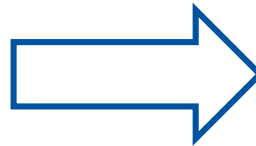
$$D = -(Y_{123,123})^{-1} * Y_{123,456}$$

$$Y = \begin{bmatrix} Y_{123,123} & Y_{123,456} \\ Y_{456,123} & Y_{456,456} \end{bmatrix}$$

Federico Milano, Álvaro Ortega: Frequency Divider
IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 32, NO. 2, MARCH 2017

Modell alapú prediktív szabályozás szinkronkonverterrel

$$X = \begin{bmatrix} X_1(k) \\ X_2(k) \\ X_3(k) \\ X_1(k+1) \\ X_2(k+1) \\ \dots \\ X_1(k+H_p) \\ X_2(k+H_p) \\ X_3(k+H_p) \end{bmatrix}$$

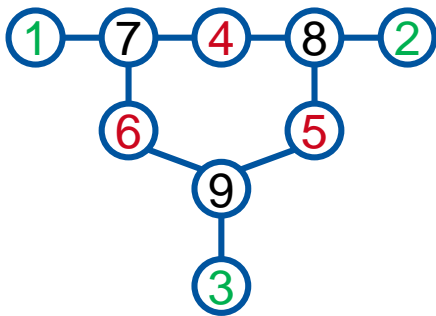
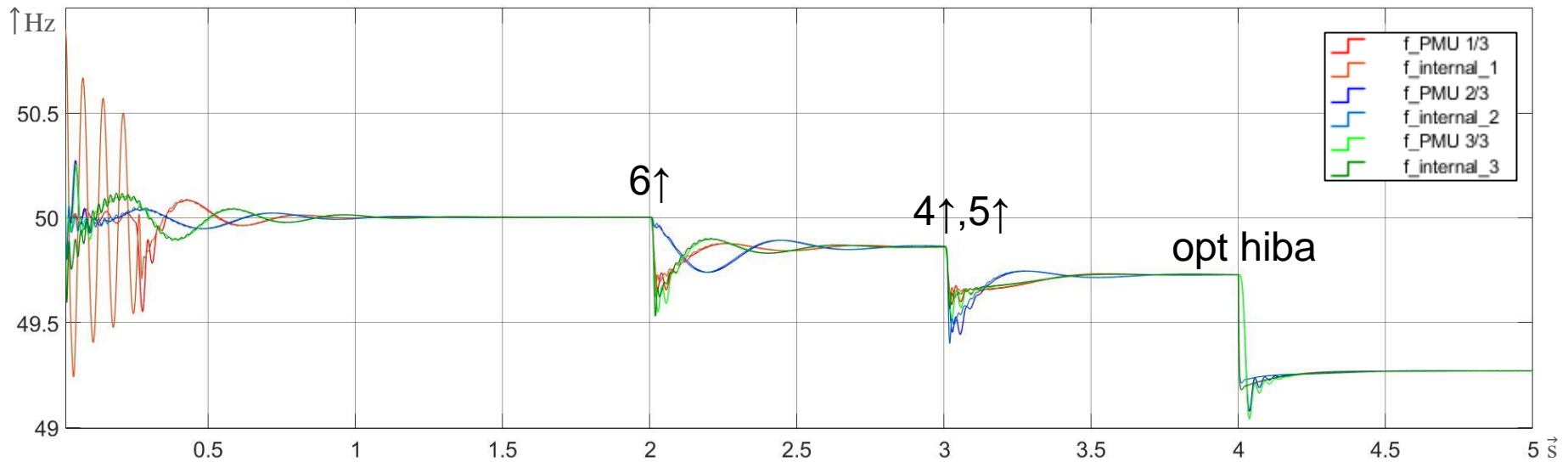


$$X = \begin{bmatrix} X_{11}(k) \\ X_{12}(k) \\ X_{13}(k) \\ X_{21}(k) \\ X_{22}(k) \\ X_{23}(k) \\ X_{31}(k) \\ X_{32}(k) \\ X_{33}(k) \\ X_{11}(k+1) \\ X_{12}(k+1) \\ X_{13}(k+1) \\ X_{21}(k+1) \\ \dots \\ X_{23}(k+H_p) \\ X_{31}(k+H_p) \\ X_{32}(k+H_p) \\ X_{33}(k+H_p) \end{bmatrix}$$

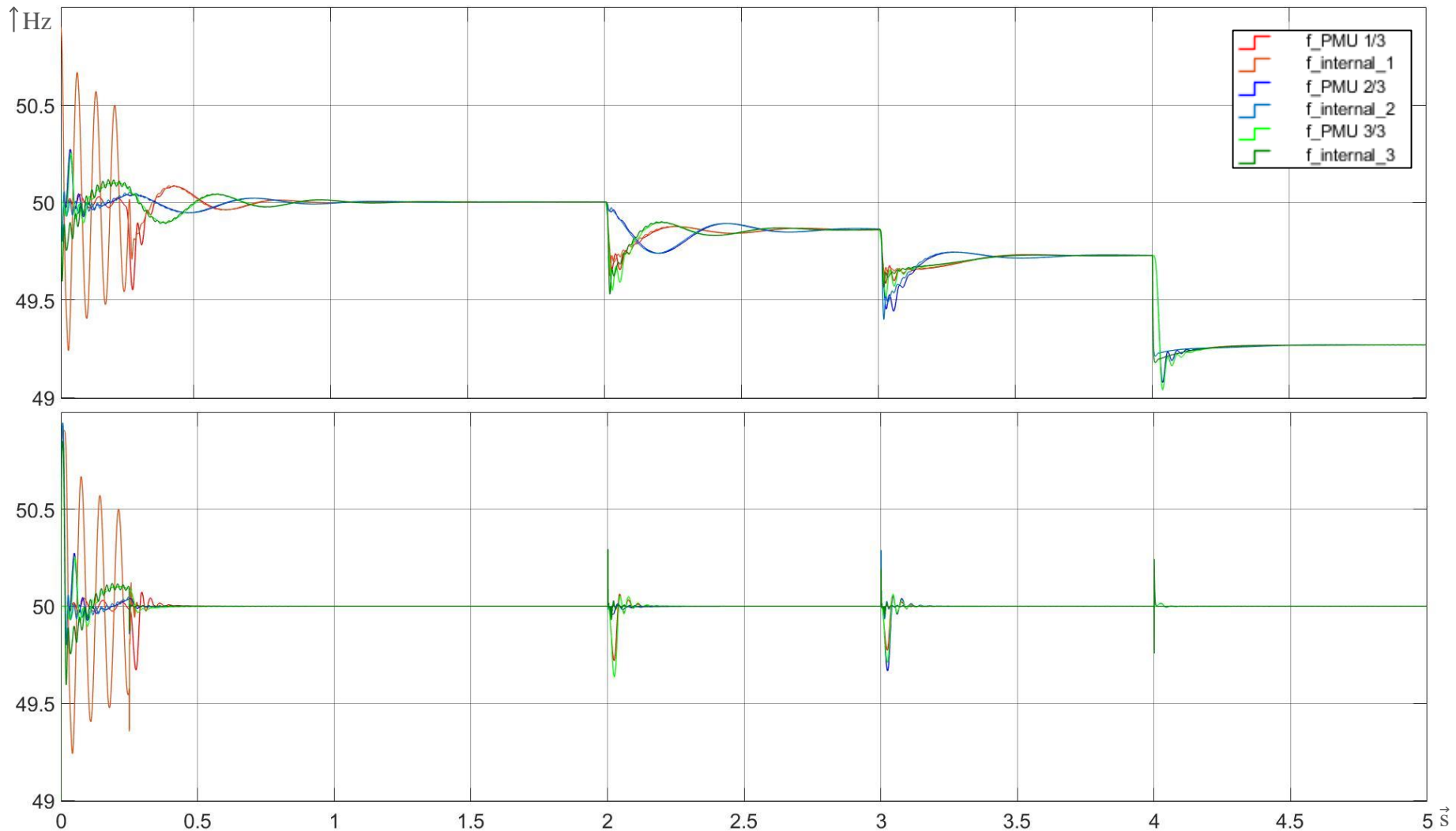
Groupings on the right side of the matrix:

- Rows 1-3: $X_{11}(k), X_{12}(k), X_{13}(k)$ are grouped with a bracket labeled "1".
- Rows 4-6: $X_{21}(k), X_{22}(k), X_{23}(k)$ are grouped with a bracket labeled "2".
- Rows 7-9: $X_{31}(k), X_{32}(k), X_{33}(k)$ are grouped with a bracket labeled "3".
- Rows 10-12: $X_{11}(k+1), X_{12}(k+1), X_{13}(k+1)$ are grouped with a bracket labeled "1".

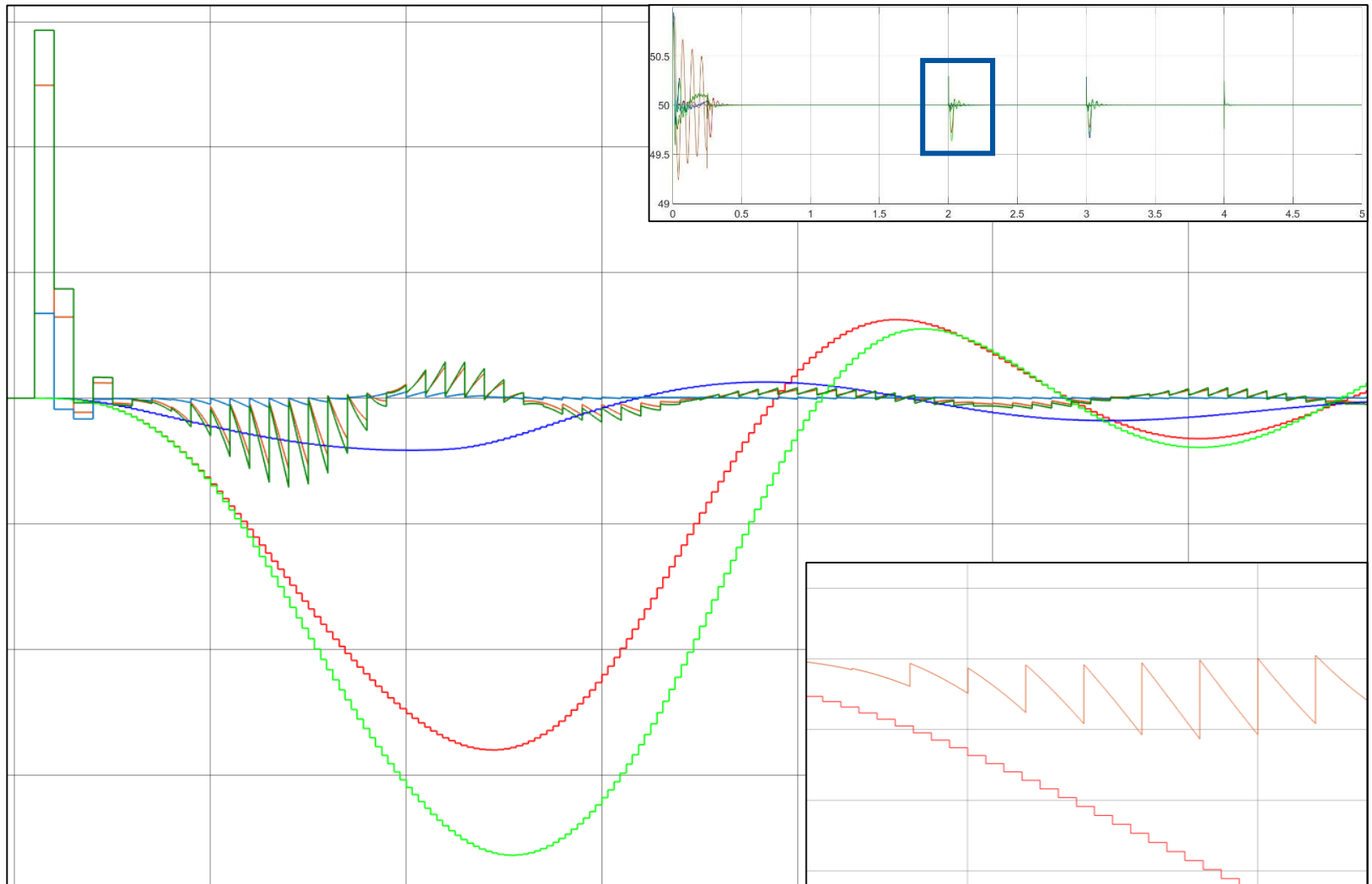
Modell alapú prediktív szabályozás szinkronkonverterrel



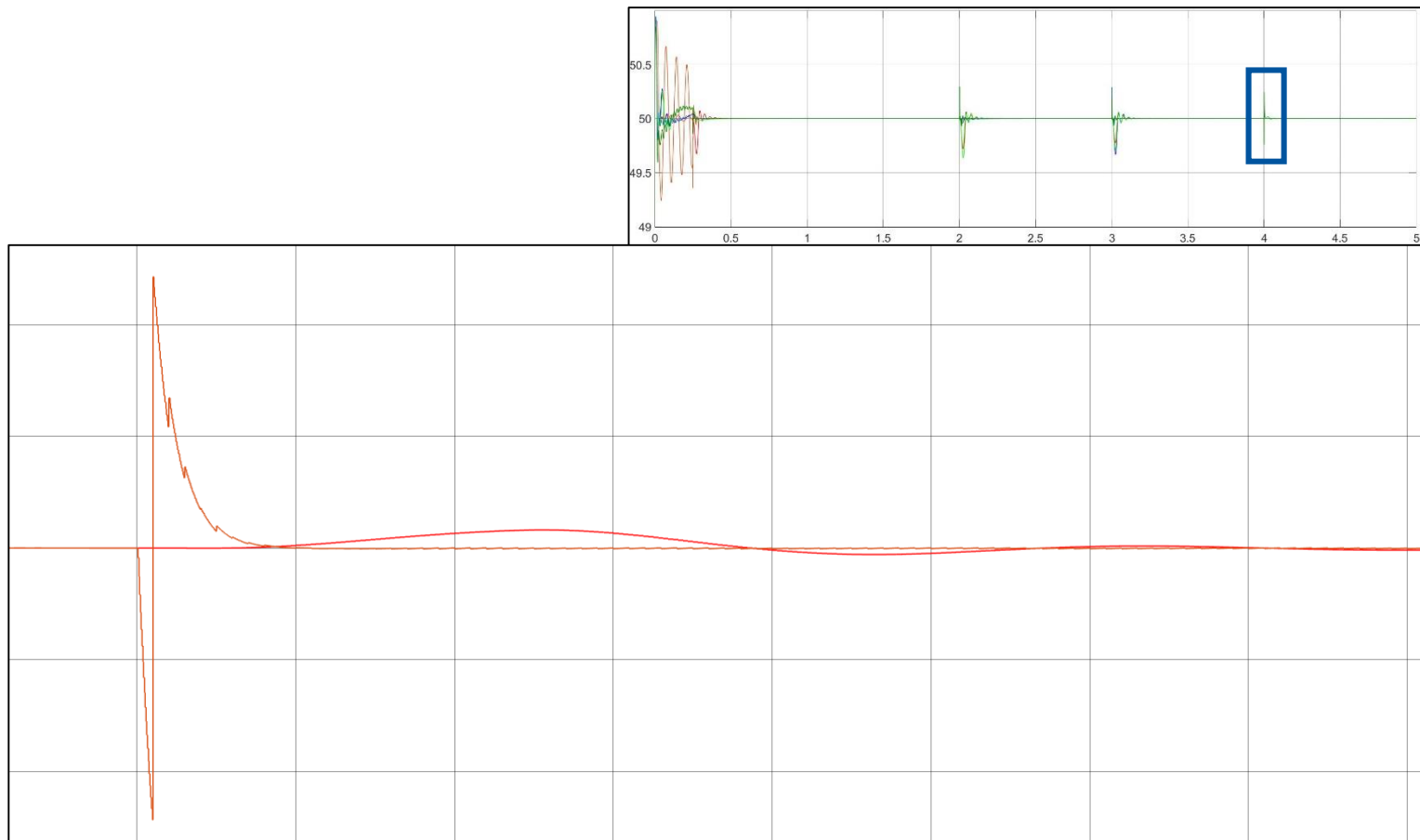
Modell alapú prediktív szabályozás szinkronkonverterrel



Eredmények

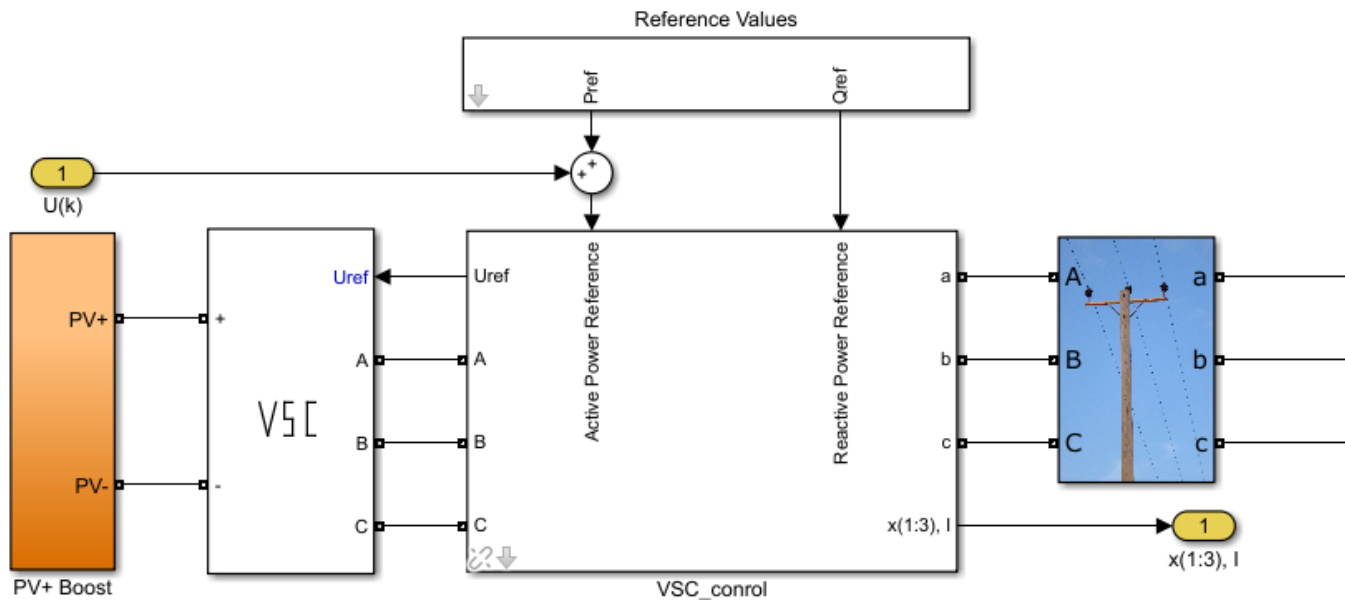


Eredmények



Hogyan tovább?

- Vizsgálatok
- Robusztusság
- Elosztott MPC



Köszönöm a figyelmet!

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