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Traditio et Innovatio

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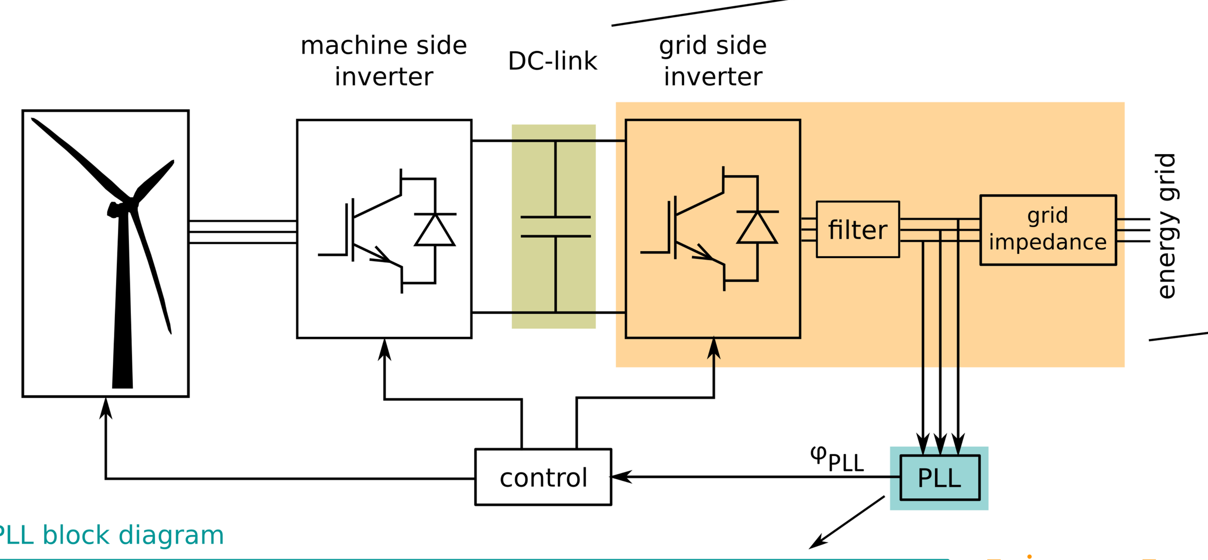
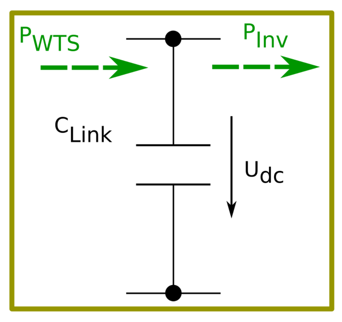
Lyapunov-Based Control for Grid Side Inverters of Wind Turbine Systems

System Description and Modelling

Wind Turbine System with full scale back-to-back converter, consisting of:

- DC-link circuit
- grid side inverter with output filter
- Phase-locked loop (PLL)

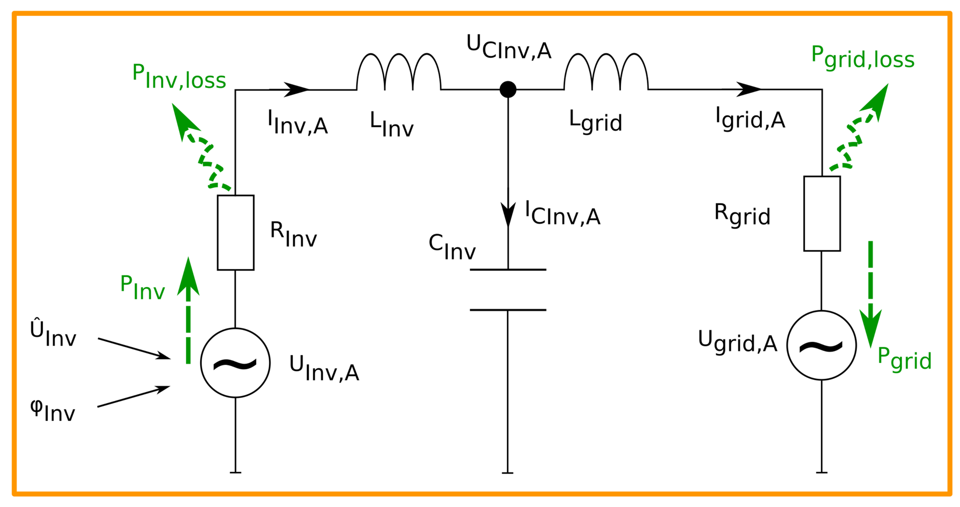




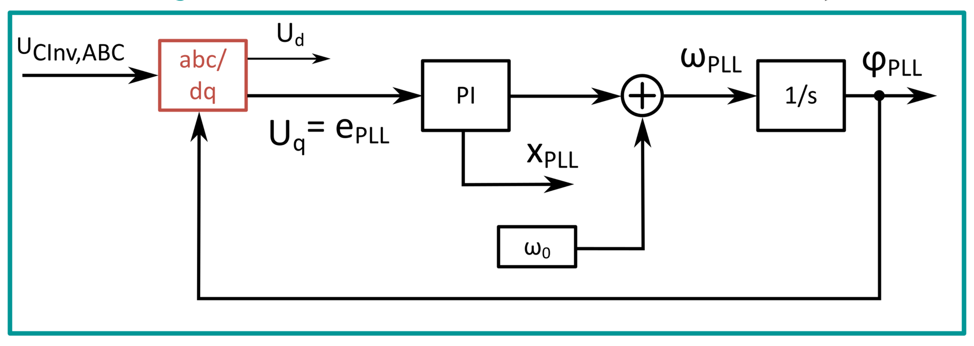
DC-link circuit

$$\dot{U}_{dc}^2 = \frac{2}{C_{Link}}(P_{WTS} - P_{Inv})$$

equivalent circuit (phase A)



PLL block diagram

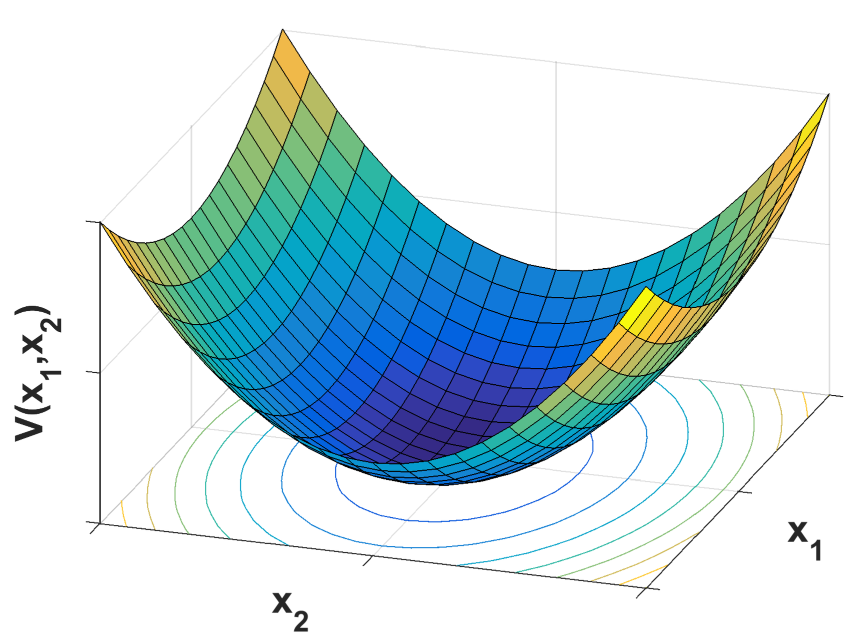


$$\begin{bmatrix} \dot{I}_{grid,A} \\ \dot{I}_{Inv,A} \\ \dot{U}_{CInv,A} \end{bmatrix} = \begin{bmatrix} -\frac{R_{grid}}{L_{grid}} & 0 & \frac{1}{L_{grid}} \\ 0 & -\frac{R_{Inv}}{L_{Inv}} & -\frac{1}{L_{Inv}} \\ \frac{1}{C_{Inv}} & -\frac{1}{C_{Inv}} & 0 \end{bmatrix} \begin{bmatrix} I_{grid,A} \\ I_{Inv,A} \\ U_{CInv,A} \end{bmatrix} + \begin{bmatrix} -\frac{1}{L_{grid}} \\ 0 \\ 0 \end{bmatrix} U_{grid,A} + \begin{bmatrix} 0 \\ \frac{1}{L_{Inv}} \\ 0 \end{bmatrix} U_{Inv,A}$$

$$\dot{x}_{PLL} = K_I \cdot U_q$$
$$\dot{\varphi}_{PLL} = x_{PLL} + K_P \cdot U_q + \omega_0$$

Lyapunov Stability Theory

Basic idea: stable operating point is characterized by an energy minimum



Lyapunov function represents energy of the system: $V(x) = \sum_{i=1}^{n} E(x_i)$

Stability condition: $\dot{V}(x) = \dot{x}^T \cdot \frac{\partial V(x)}{\partial x} \overset{!}{<} 0$

Objective: trajectories $x(t)$ tend towards an energy minimum

Application to grid side inverter: $x = [I_{grid,ABC}\ I_{Inv,ABC}\ U_{CInv,ABC}\ U_{dc} - 1100]^T$

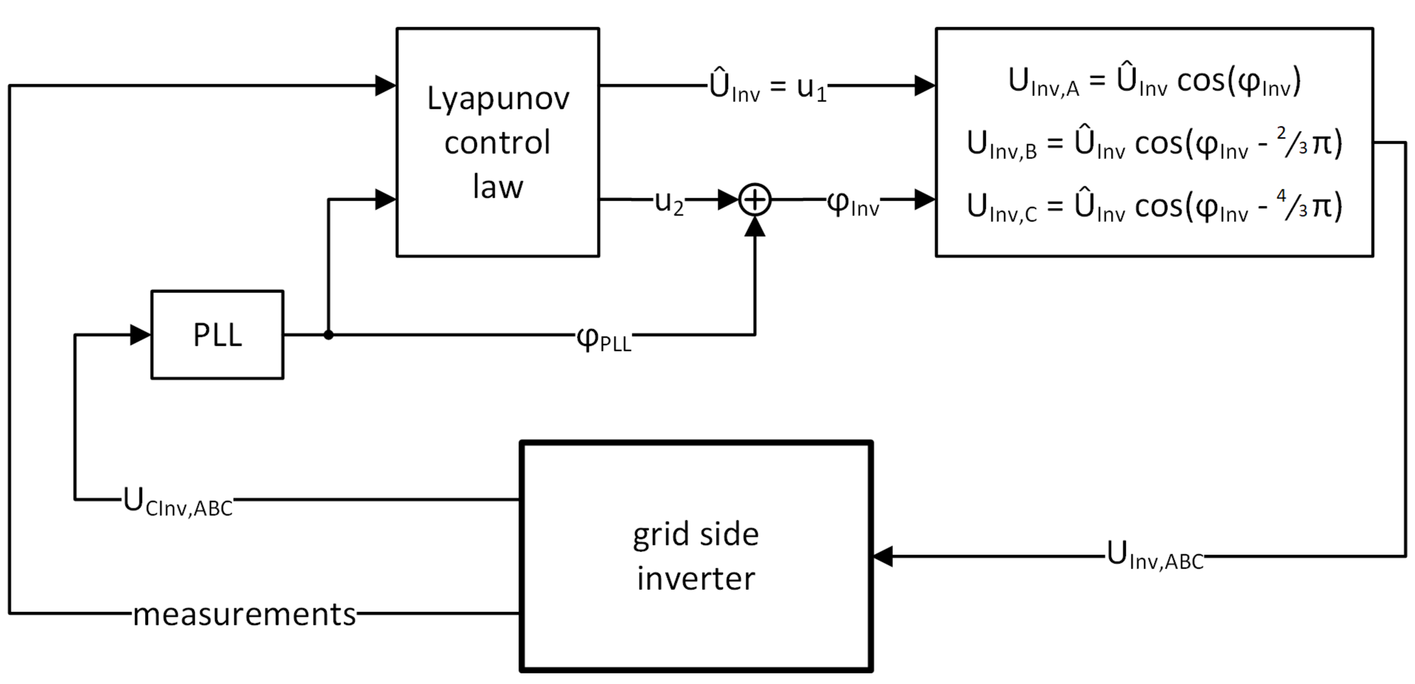
choose quadratic Lyapunov function: $V(x) = x^T R x$

determine control inputs $\hat{U}_{Inv}$ and φ_{Inv} s.t. $\dot{V}(x) < 0$

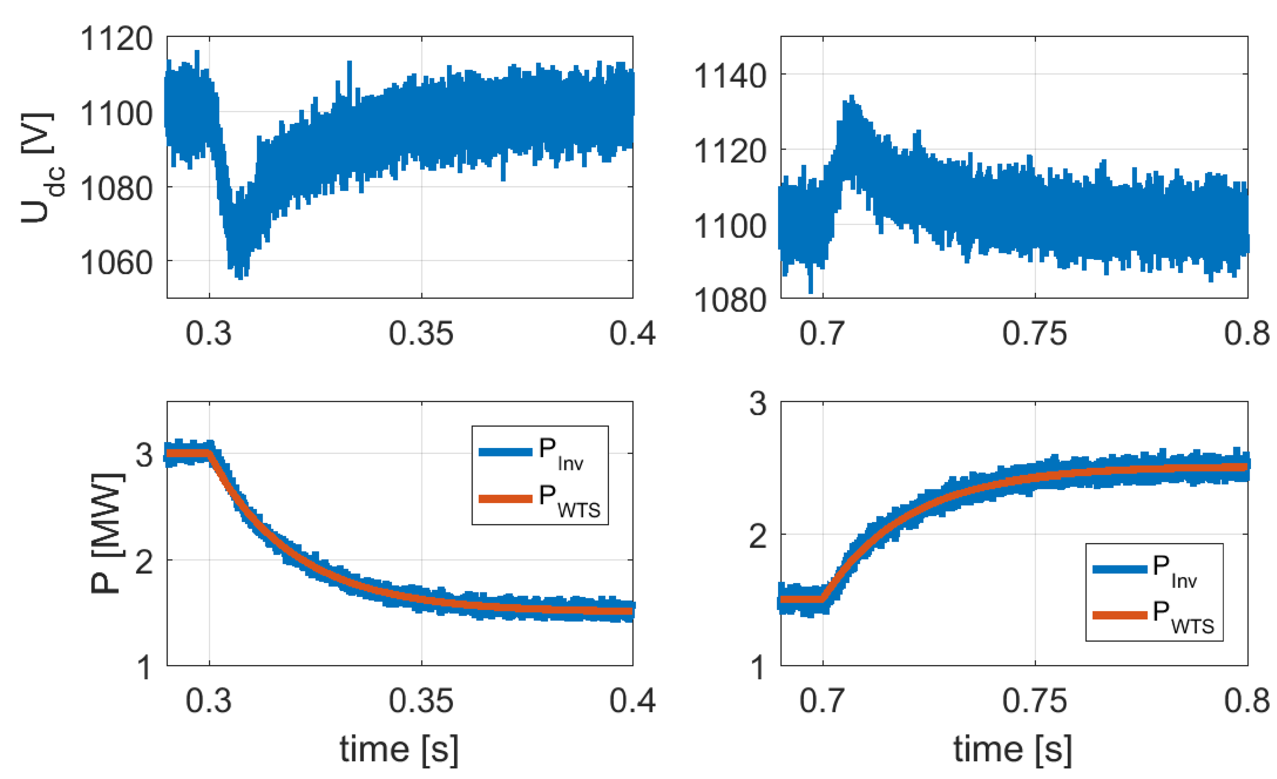
apply inverter voltage: $U_{Inv,A} = \hat{U}_{Inv} \cos\underbrace{(\varphi_{PLL} + u_2)}_{\varphi_{Inv}}$

Controller and Simulation Results

Controller block diagram:



Simulation Results: DC-link voltage U_{dc}, excited by changes of wind turbine power P_{WTS}



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