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# **Microgrid PQ control with Guaranteed Trajectory: Model-based Analysis, Physics-informed Learning, and Hardware-in-the-loop Experiment**

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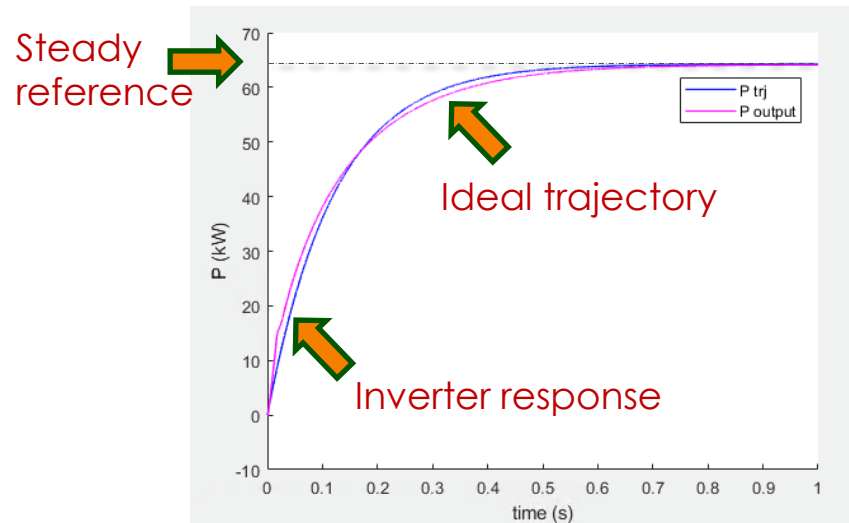
# Scope: Guaranteed Trajectory

## Scope

Assume a step input, the response of PQ output can be controlled smoothly and accurately

$$y(t) = 1 - e^{-t/\tau}$$

Where  $\tau$  is response time constant that can be freely assigned.



## Mythology

Use **adaptive** PI controller with time-varying gains:

$$k_p = f(t); k_i = g(t)$$

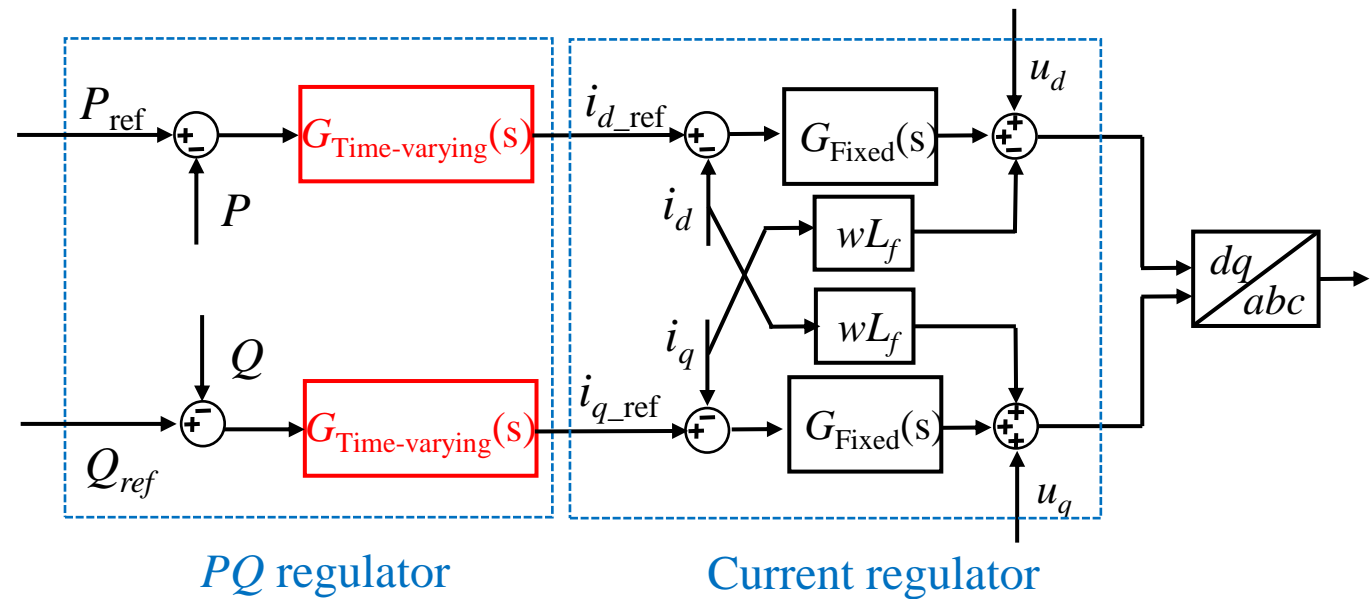
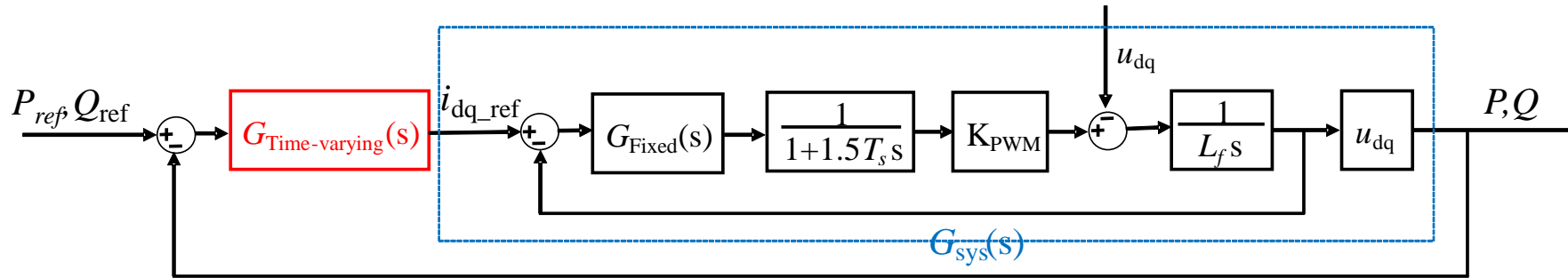


Diagram of the Proposed Adaptive Inverter PQ Controller

# Model-based Analysis



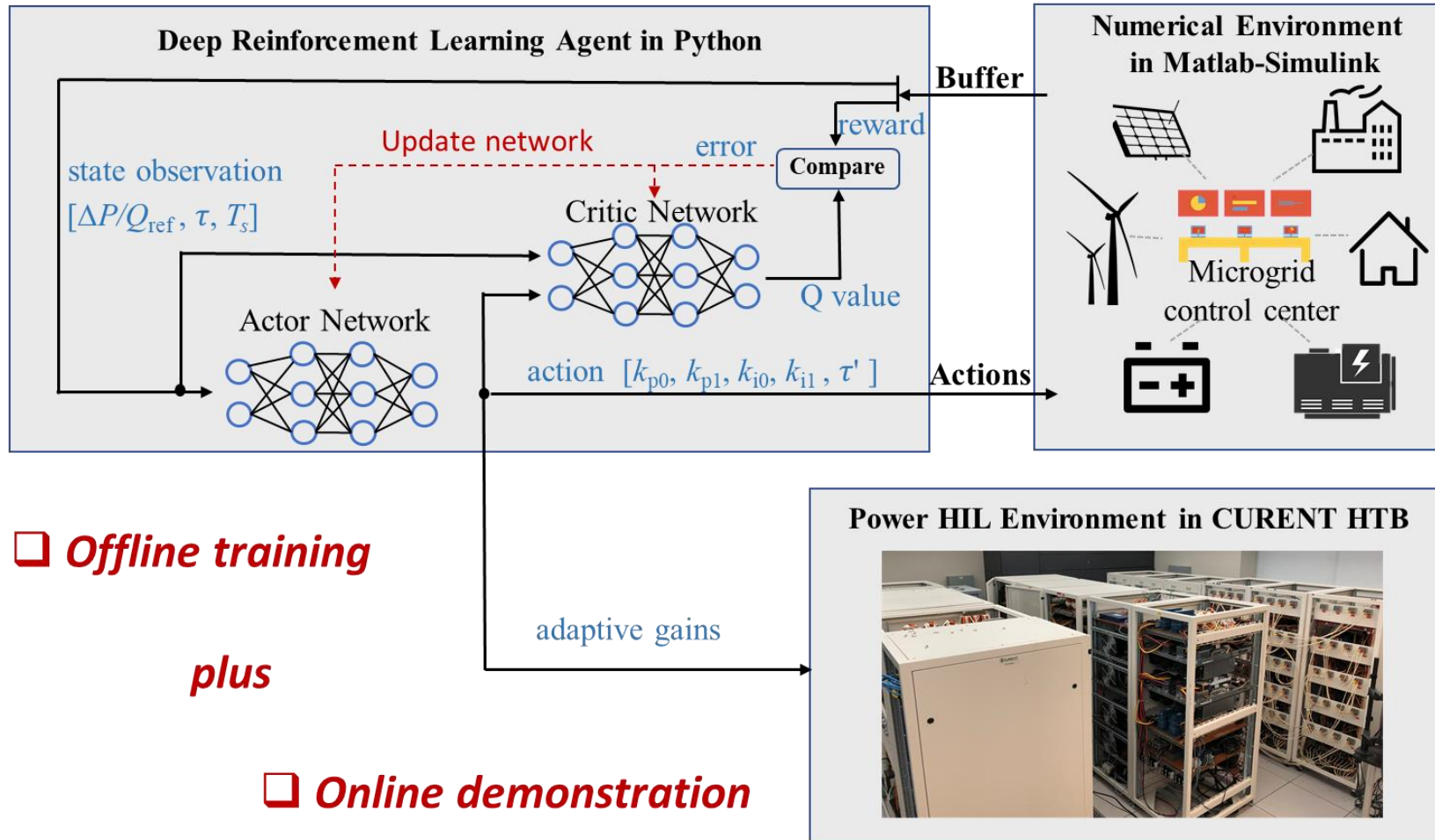
Inverter-based P-Q control diagram

## □ Analytical expression of PI gains

$$\begin{cases} k_p(t) = k_{p0} + k_{p1} e^{-t/\tau'} \\ k_i(t) = k_{i0} + k_{i1} e^{-t/\tau'} \end{cases} \quad \text{Where} \quad \begin{cases} k_{p0} = \frac{L_f (1 - 1.5T_s / \tau)}{\tau K_{PWM} (k_{i2} / k_{p2} - 1 / \tau)} \\ k_{p1} = \frac{L_f}{\tau K_{PWM}} \left( 1.5T_s + \frac{1.5T_s / \tau - 1}{k_{i2} / k_{p2} - 1 / \tau} \right) \\ k_{i0} = 0, \quad k_{i1} = k_{p1} / \tau \\ \tau' = k_{p2} / k_{i2} \end{cases}$$

**Question: What if  $G_{sys}(s)$  is unavailable or inaccurate?**

# Physics-informed Learning and HIL Test



- Model-based analysis reduce learning space from **function space** to **real space**

$$\begin{cases} k_p(t) = k_{p0} + k_{p1} e^{-t/\tau'} \\ k_i(t) = k_{i0} + k_{i1} e^{-t/\tau'} \end{cases}$$



$$k_p(t), k_i(t) \in f(t)$$

$$k_{p0}, k_{p1}, k_{i0}, k_{i1} \in \mathbf{R}$$

Diagram of Physics-informed Reinforcement Learning (RL) in the Numerical Simulator and Power HIL demonstration in HTB

# Test Microgrid and Training Results

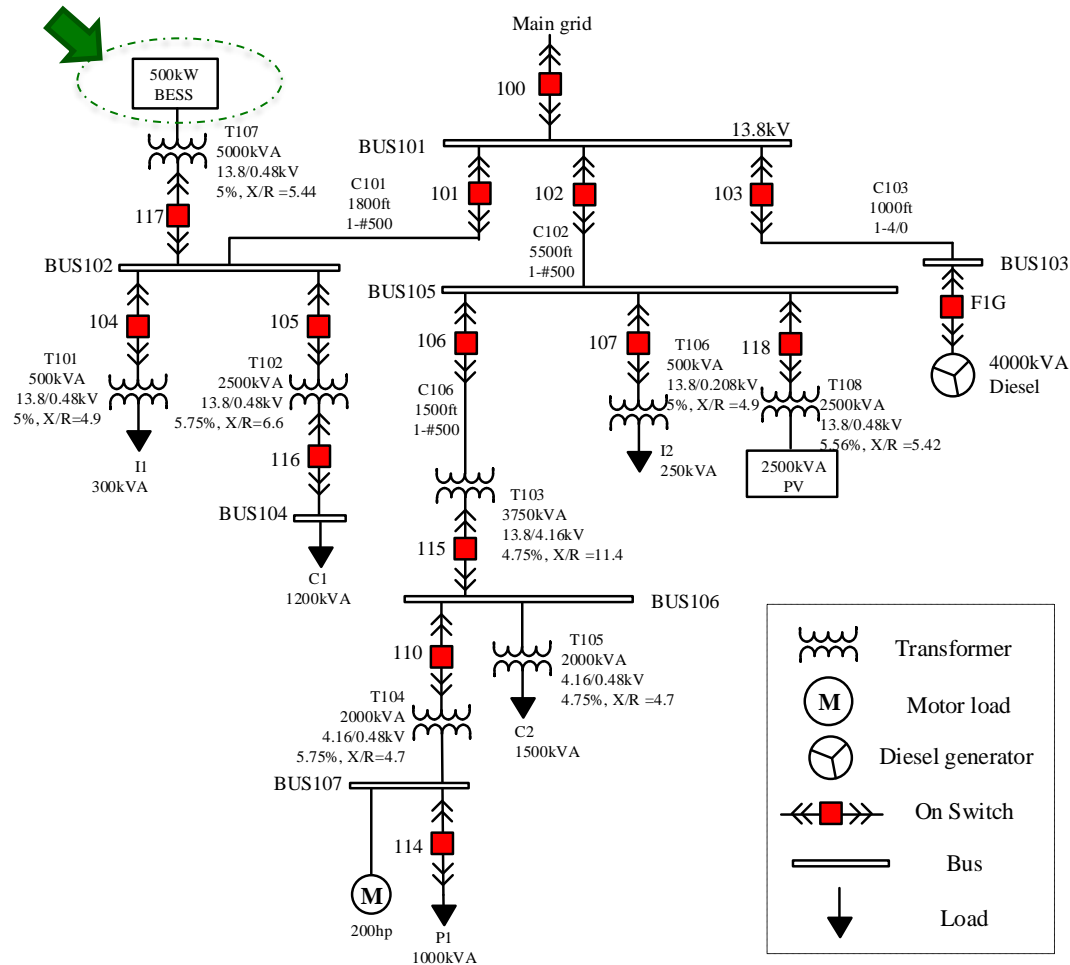
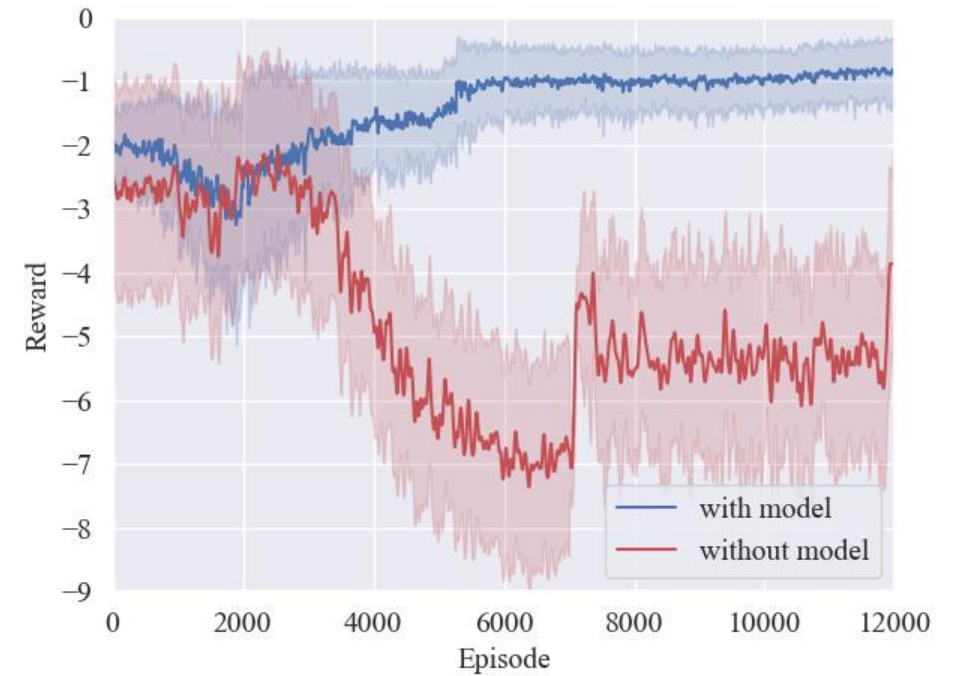
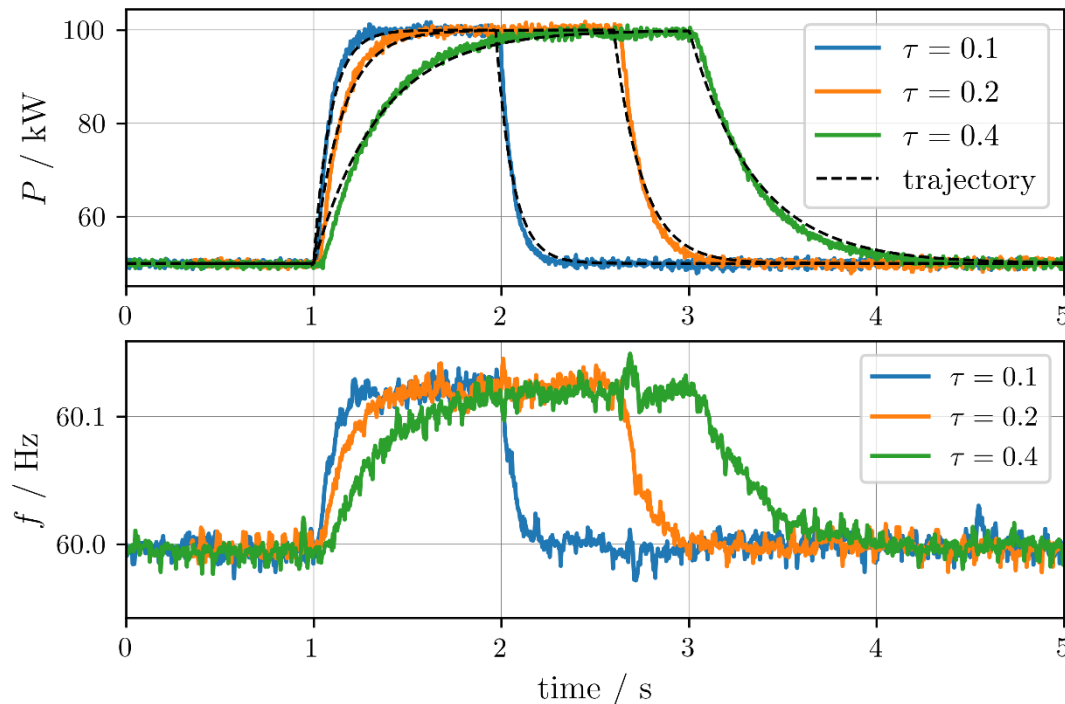


Diagram of modified Banshee microgrid

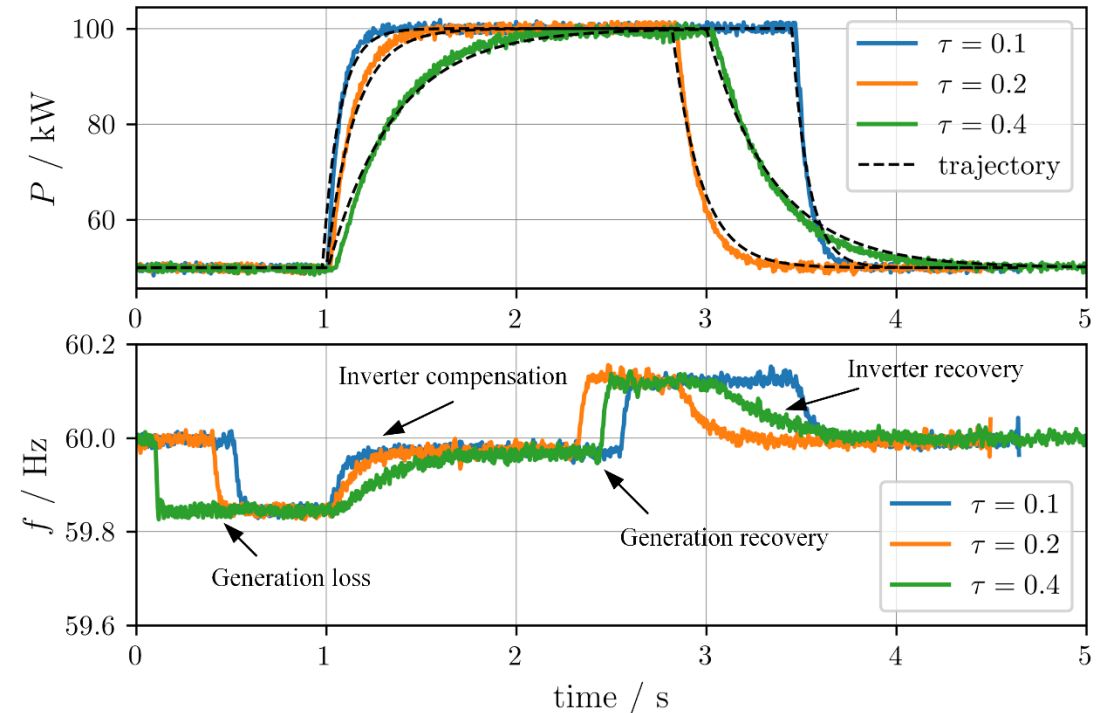


Reward curve with and without model-based analysis

# Validation in CURENT HTB and Conclusions



**Scheduling reference change**



**Generation reduction & recovery**

- Inverters can be freely assigned any time constant and respond either slow or fast to customized commands.
- The proposed control algorithm is valid under scheduling reference change and generation reduction and recovery.

# Acknowledgements

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