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

2023 CURENT Industry Conference

April 18, 2023

Buxin She, Fangxing(Fran) Li
The University of Tennessee Knoxville

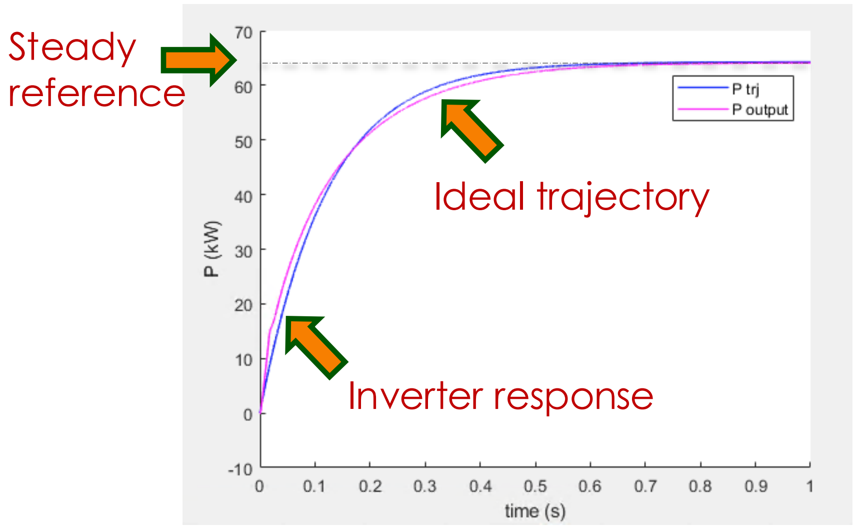
Scope: Guaranteed Trajectory

❑ Scope

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

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

Where τ is response time constant that can be freely assigned.



❑ Mythology

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

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

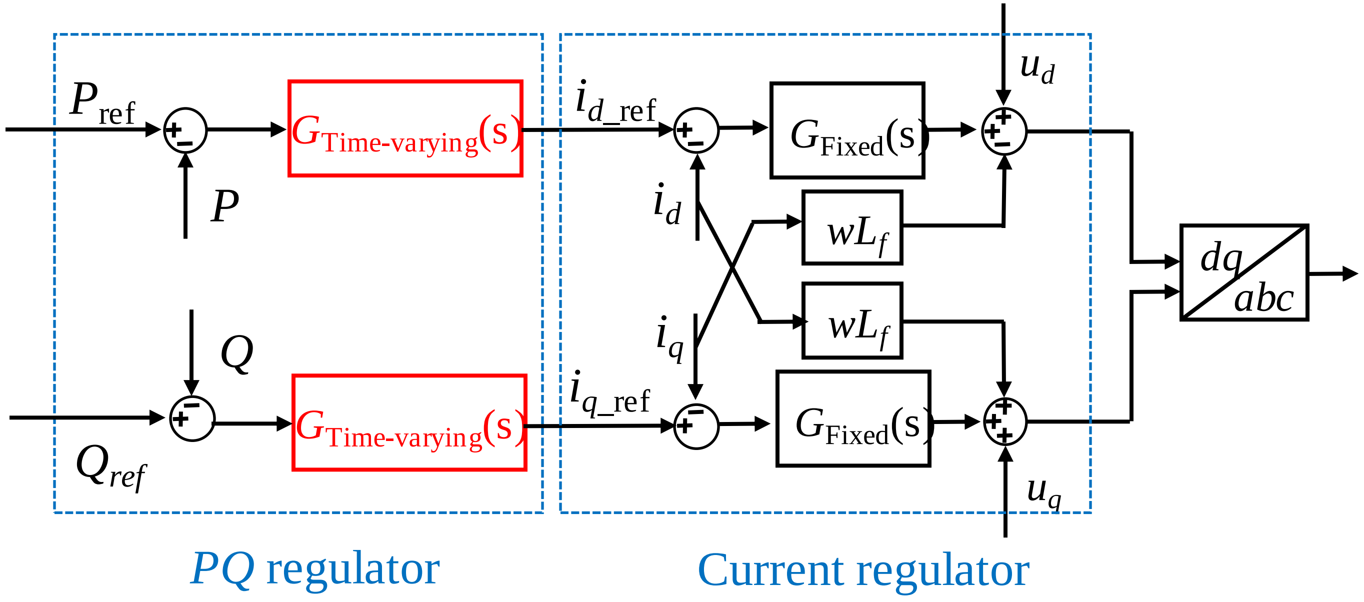
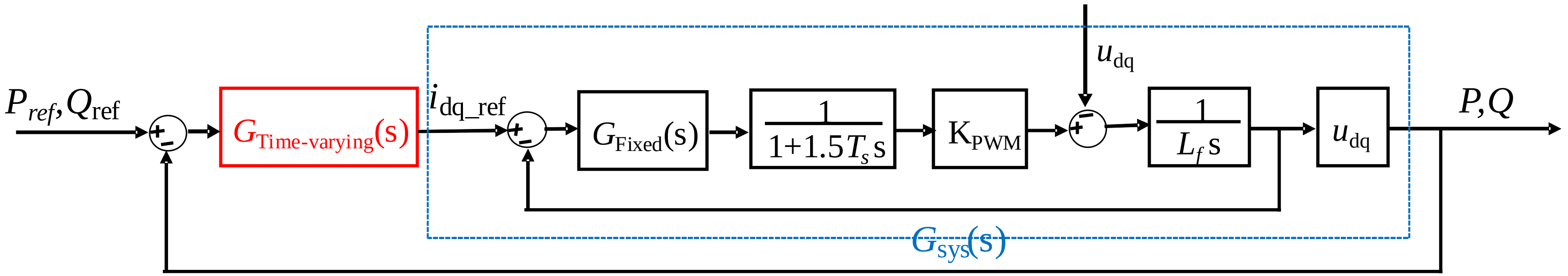


Diagram of the Proposed Adaptive Inverter PQ Controller

CURENT

Model-based Analysis



Inverter-based P-Q control diagram

- **Analytical expression of PI gains**

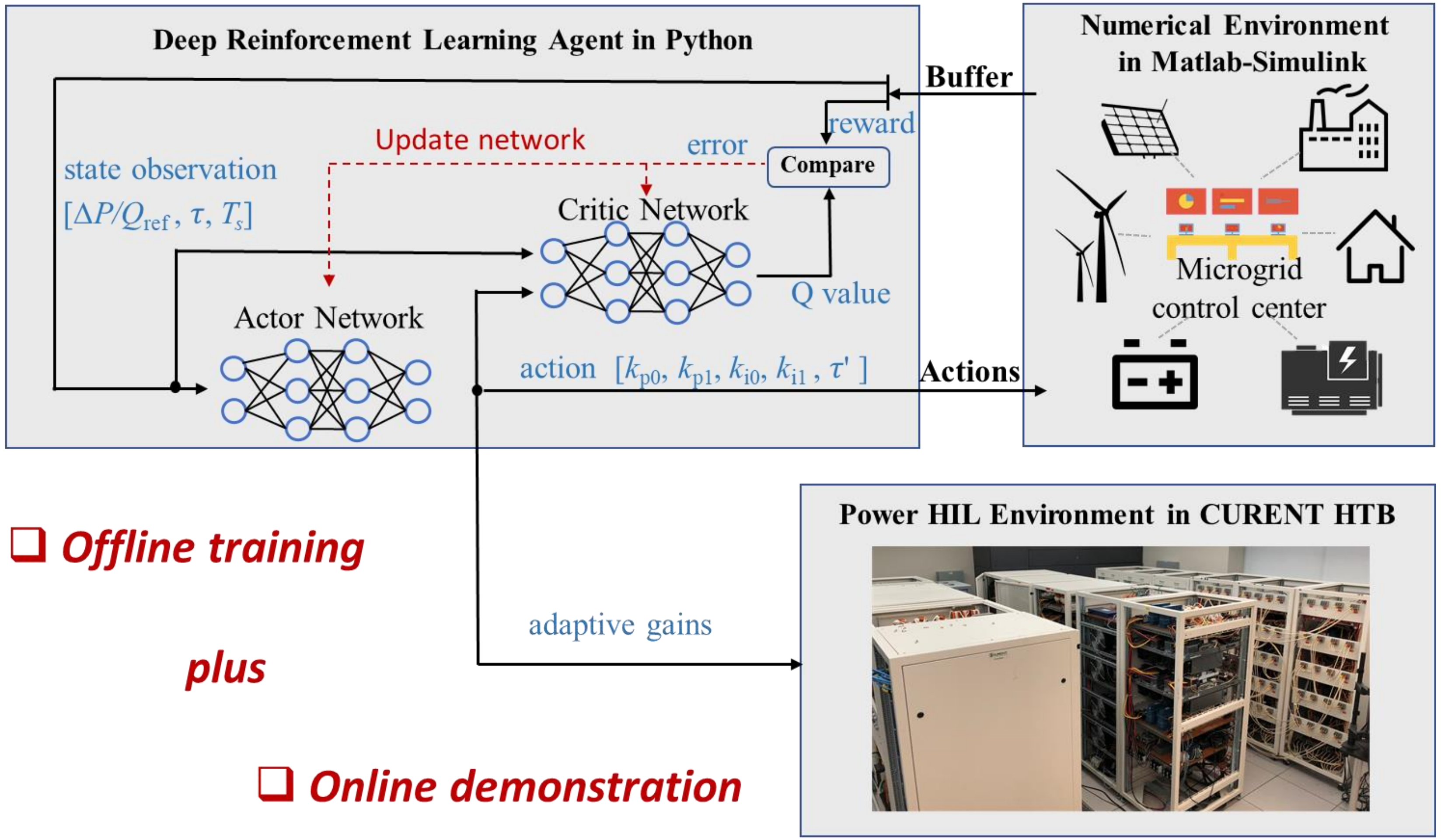
$$\begin{cases} k_p(t) = k_{p0} + k_{p1} e^{-t/\tau'} \\ k_i(t) = k_{i0} + k_{i1} e^{-t/\tau'} \end{cases}$$

Where

$$\begin{cases} k_{p0} = \dfrac{L_f(1-1.5T_s/\tau)}{\tau K_{PWM}(k_{i2}/k_{p2} - 1/\tau)} \\ k_{p1} = \dfrac{L_f}{\tau K_{PWM}}\left(1.5T_s + \dfrac{1.5T_s/\tau - 1}{k_{i2}/k_{p2} - 1/\tau}\right) \\ k_{i0} = 0,\ k_{i1} = k_{p1}/\tau \\ \tau' = k_{p2}/k_{i2} \end{cases}$$

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

Physics-informed Learning and HIL Test



- ❑ ***Offline training***

plus

- ❑ ***Online demonstration***

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

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

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

$$k_p(t), k_i(t) \in \boldsymbol{f}(t)$$

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

CURENT

Test Microgrid and Training Results

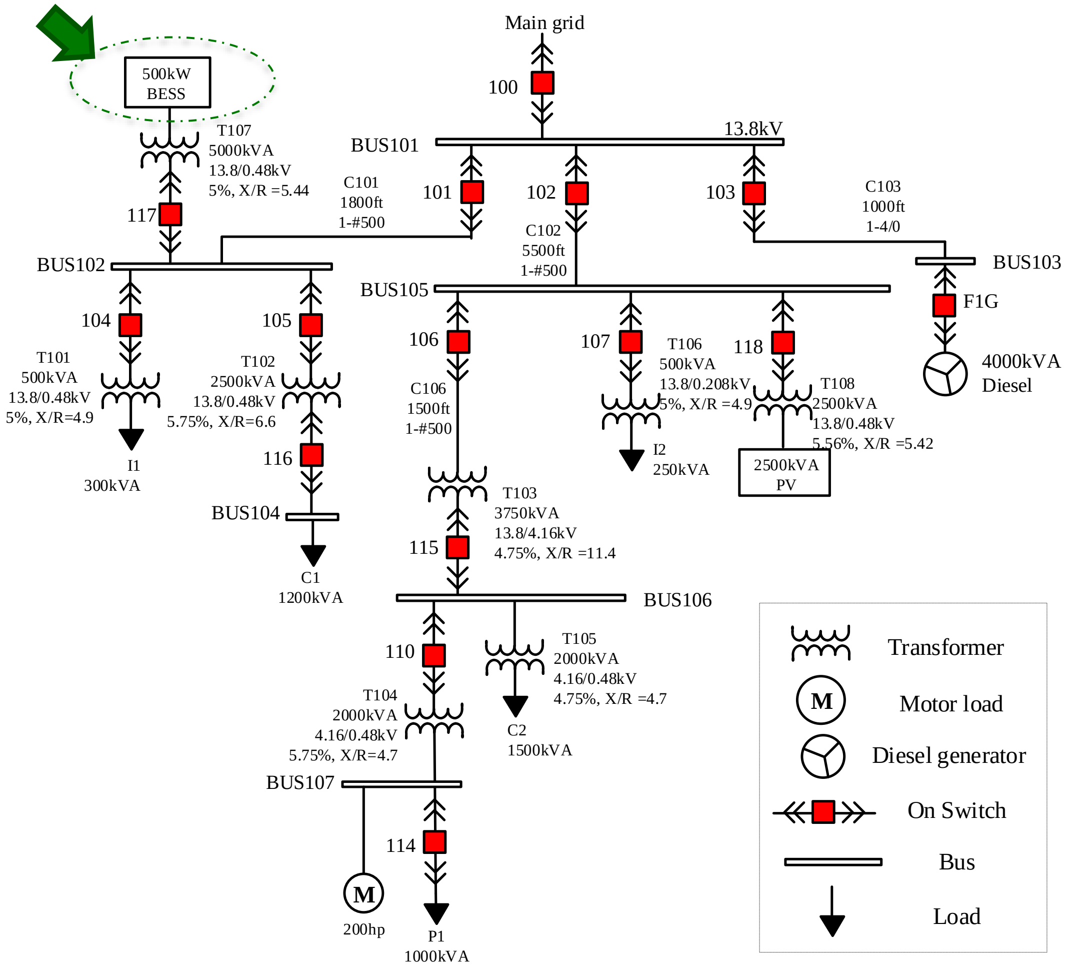
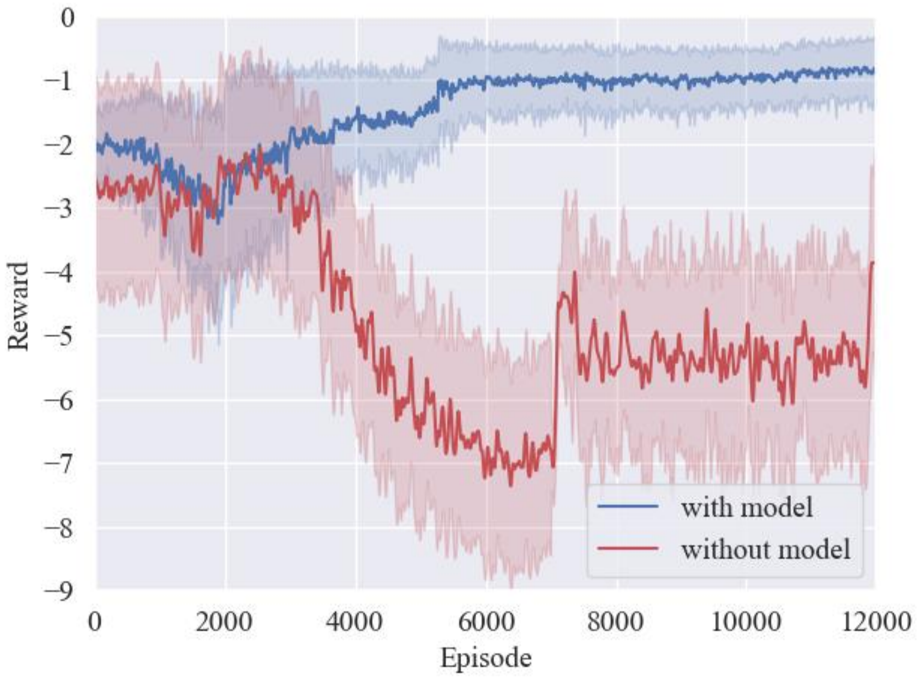
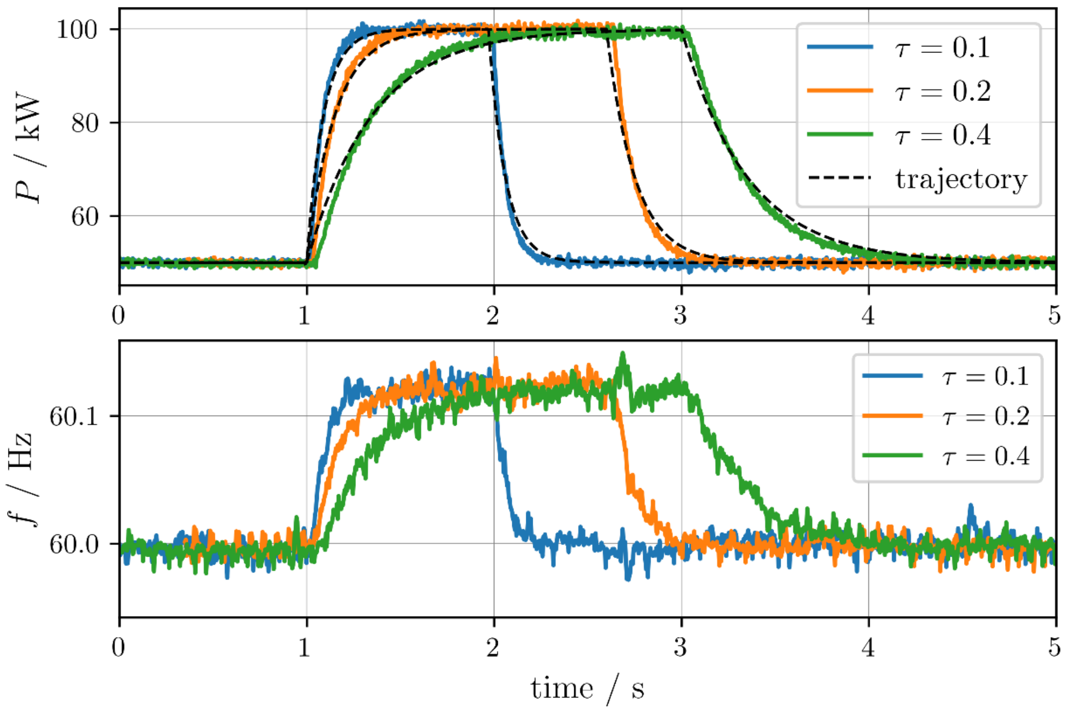


Diagram of modified Banshee microgrid

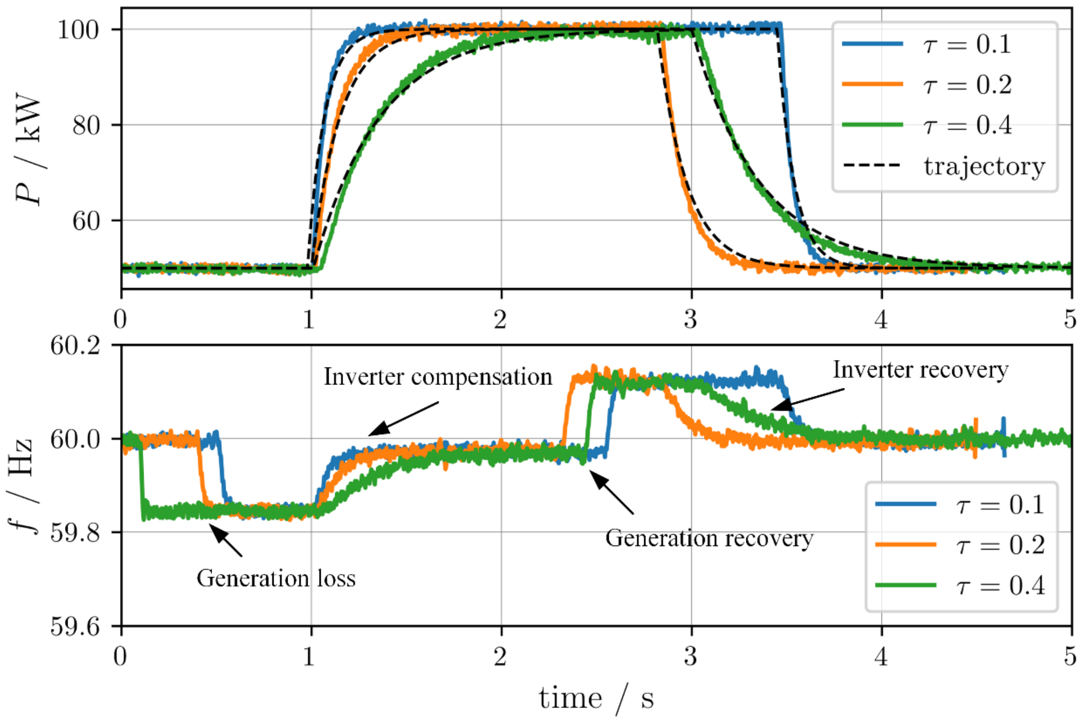


Reward curve with and without model-based analysis

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.

CURENT

Acknowledgements

This work was supported by US DOD ESTCP program under the grant number EW20-5331

Contributing authors:

Buxin She, Fangxing(Fran) Li, Hantao Cui, Hang Shuai, Oroghene Oboreh-Snapps, Rui Bo, Nattapat Praisuwanna, Jingxin Wang, Leon M. Tolbert

CURENT