Real-time Inertia Estimation in Kauai Island Using Probing-based Method: Field Implementation and Demonstration

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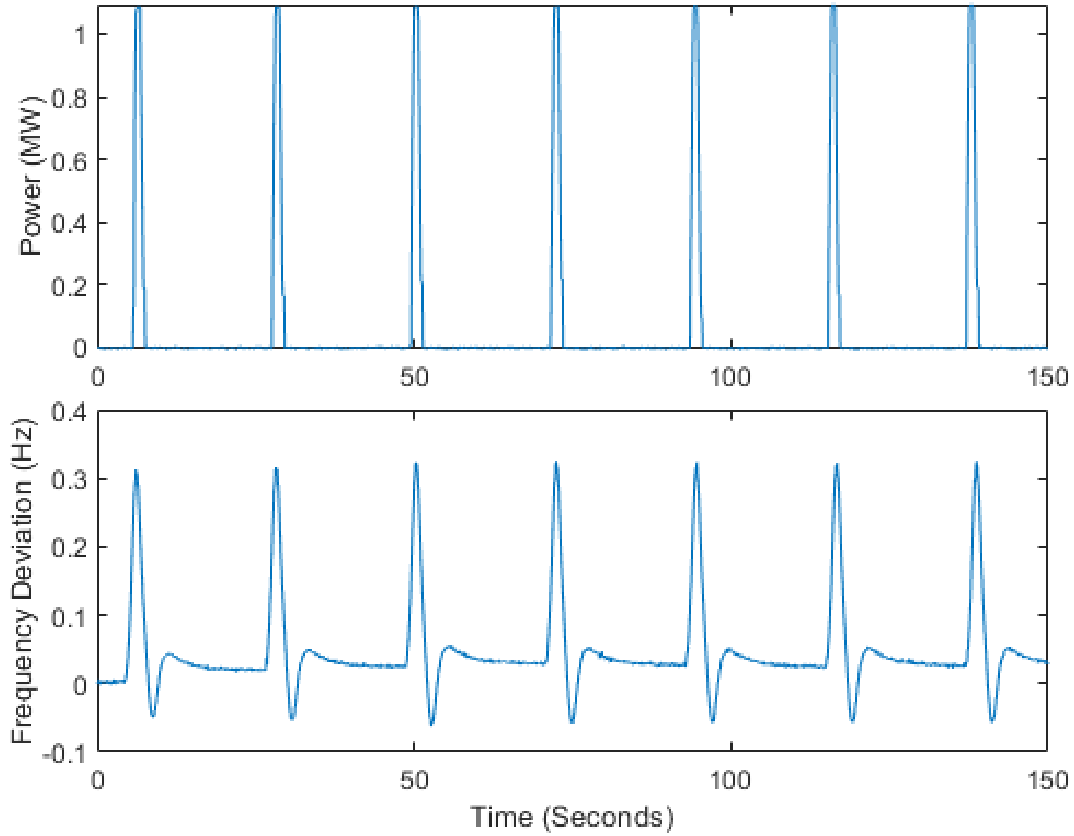
Inertia Estimation Methods Overview

Methods	Pros	Cons
Dispatch-based	Simple Can be implemented based on SCADA or EMS data.	IBR/load inertia not considered. Load inertia not include
Event-based	Most accurate. Could factor in other contributions	Needs to wait for the occurrence of an event.
Ambient-based	Real-time inertia estimation.	Accuracy is limited, need calibration with known values
Probing-based	Can be estimated at grid operators' desired time by controlled probing injections.	Requires control hardware to produce the probe signal

Probing-based Real-time Inertia Estimation

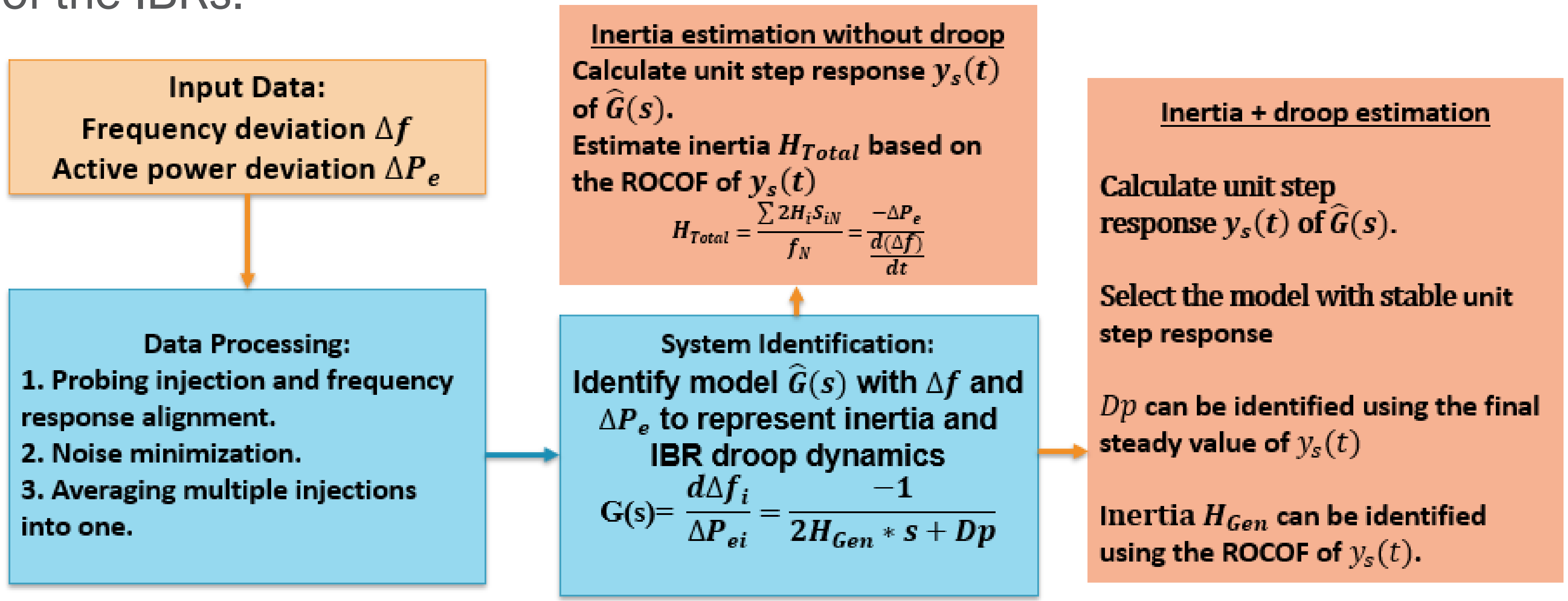
The basic idea of probing-based inertia estimation is to utilize controllable inverters in the field to **inject active power pulses** into the grid and estimate system inertia using **frequency measurements**.



Example: Frequency deviation during probing test in an ideal no-noise synthetic grid model

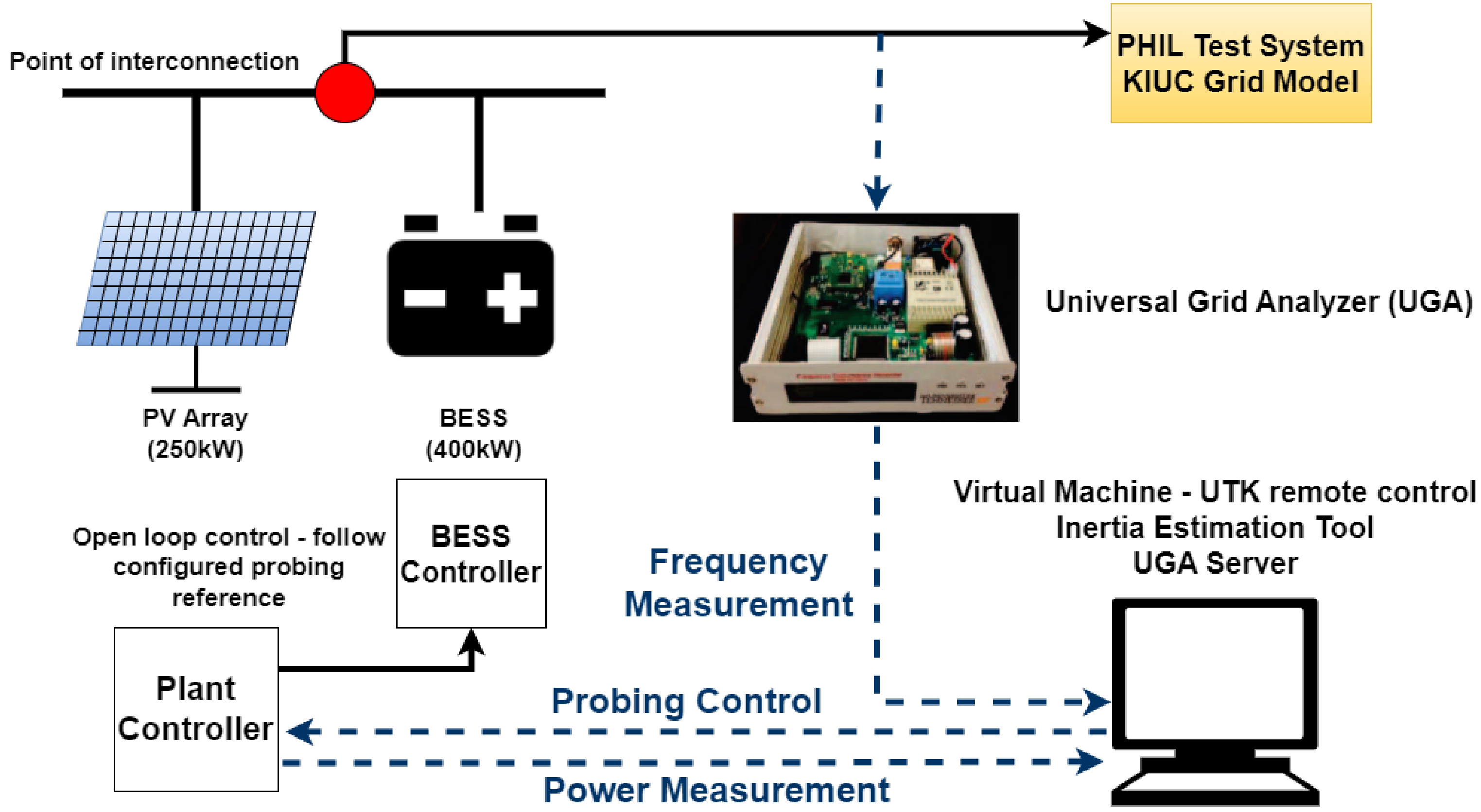
Probing-based Real-time Inertia Estimation

- Two sets of estimation algorithms that based on system identification are developed:
  - Inertia only estimation: To estimate system inertia from SGs and provide insights on assessing the artificial inertia contribution from the IBRs.
  - Inertia + droop estimation: To estimate both the SGs’ inertia contribution and the droop contribution of the IBRs.



Algorithm Validation Through PHIL

- PHIL test system with identical hardware and control as the actual Kauai Island power grid is being set up at the NREL Flatirons campus.



PHIL Test Results

- Case 1: Base case with only different SGs online and simulated noise
  - Ground truth is the sum of generator inertia because no IBRs are online.
  - The average estimation error is 2.85%.

	Case 1 - A	Case 1 - B	Case 1 - C	Case 1 - D
Ground truth inertia (MW.s)	102.046	97.5	86.347	90.847
Estimated inertia (MW.s)	105.28	99.30	90.07	88.97
Error %	**3.17%**	**1.85%**	**4.31%**	**-2.07%**

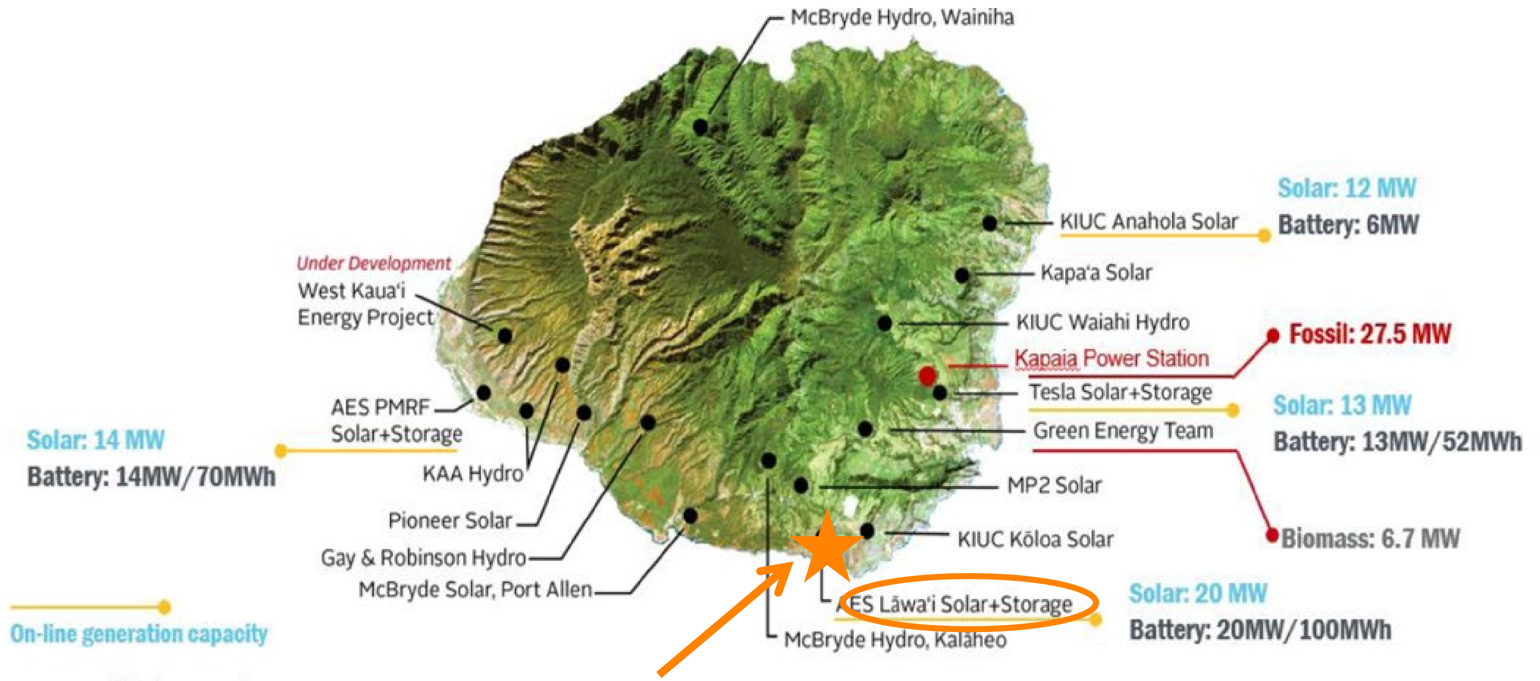
PHIL Test Results

- Case 2, 3, and 4: Different combination of online GFL & GFM IBRs
  - Estimated inertia include inertia from both SGs and GFM IBRs
  - GFL IBRs doesn't provide inertia, only provide droop
  - The average inertia estimation error is **7.03%**, droop estimation error is **3.50%**.

	Case 2 - A	Case 2 - B	Case 2 - C	Case 3	Case 4
Inertia ground truth (MW.s)	102.046	102.046	102.046	187.233	187.233
Estimated inertia (MW.s)	92.511	94.273	105.372	191.184	211.319
Error %	**-9.34%**	**-7.62%**	**3.26%**	**2.11%**	**12.86%**
Droop ground truth (MW/Hz)	8.486	6.422	4.009	8.775	16.553
Estimated droop (MW/Hz)	8.208	6.095	3.848	9.046	16.886
Error %	**-3.28%**	**-5.09%**	**-4.02%**	**3.09%**	**2.01%**

Kauai Island Field Demonstrations

- Field demonstration at Kauai Island
  - Utilizes one invertor from a centrally located solar power plant to inject probing pulses to the KIUC power grid for inertia estimation.



1 BESS inverter used for probing injection

Kauai Island Field Demonstrations

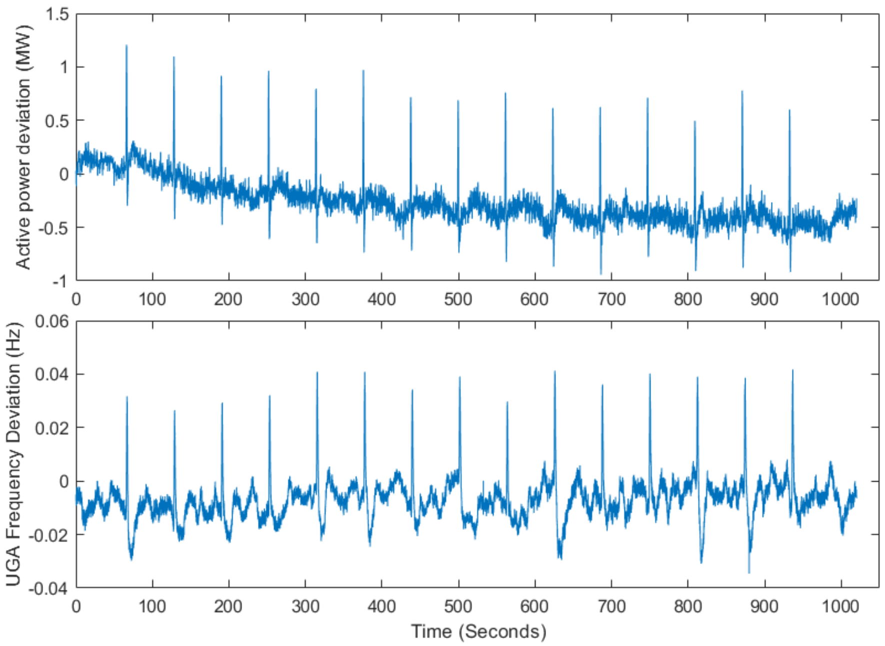
- Probing signal used for field test:
  - Each field test:
    - A series of 15 Hann-shaped signals, each with 1.4 MW, lasting 2 seconds, at 60-second intervals were injected.

- Various field tests conducted to:
  - Perform online inertia estimation under different KIUC dispatches and IBR settings.
  - Study the inertia contribution from IBRs.
  - Track inertia level changes during a 24-hour period

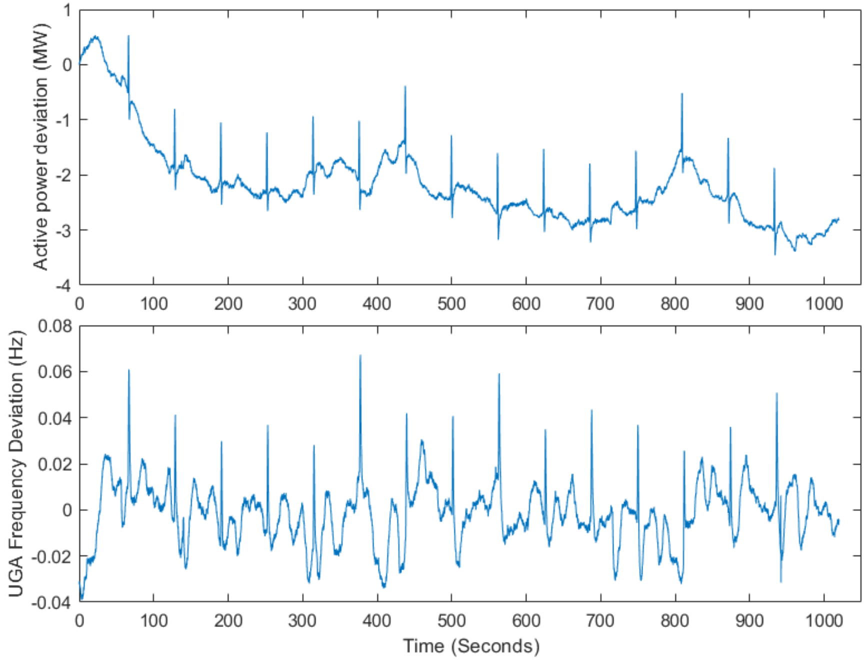
Kauai Island Field Demonstration Results

- Nighttime and morning time is more accurate, most case inertia and droop error are less than 15%~20% .
- Noon time estimation error are much larger.

Field test conducted at 12am HST

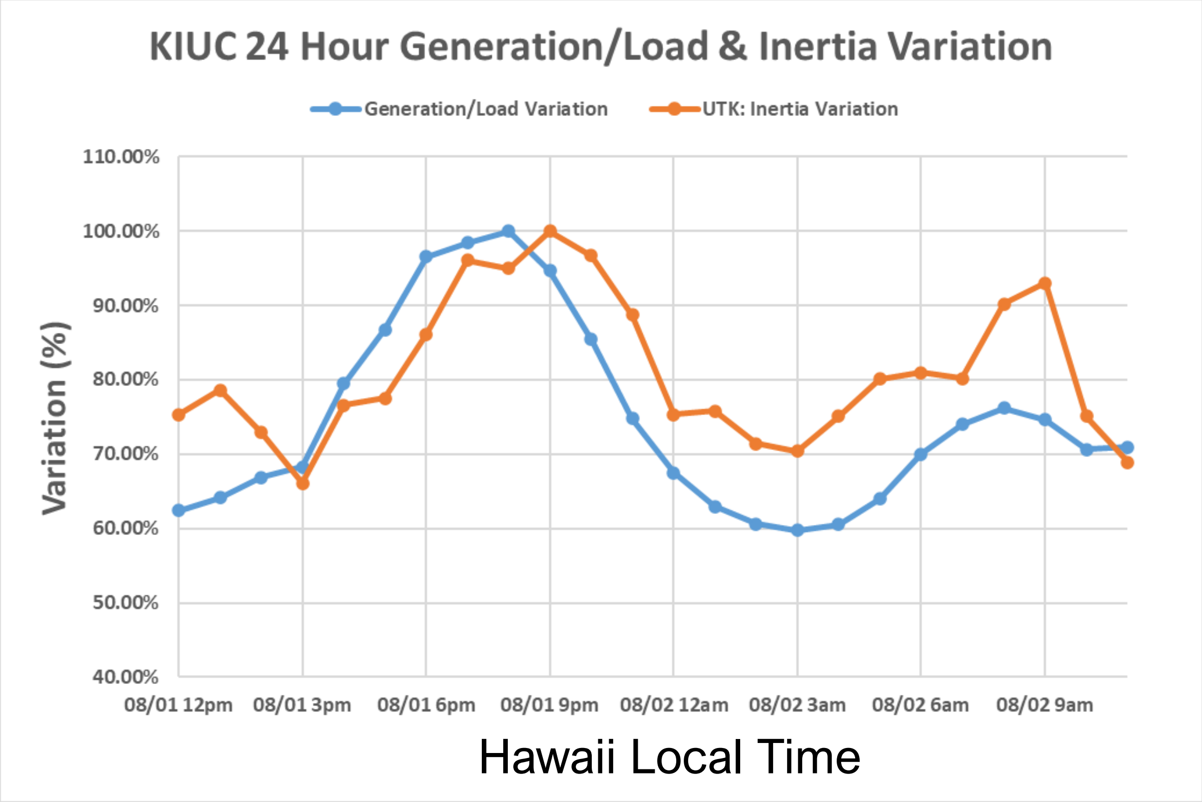


Field test conducted at 12pm HST



Kauai Island Field Demonstration Results

- KIUC inertia variation follows its generation/load variation.



Kauai Island Field Demonstration Findings

- Grid frequency noise level has a huge impact on estimated inertia
- Grid forming IBR’s virtual inertia contribution can be much larger than the vendor provided value
  - With GFM IBR offline, more frequency deviation caused by probing signals can be observed.
- 24H inertia profile matches the KIUC total generation/load variation.
  - Lowest inertia during noon when more renewables online.

Thank you!

Questions?

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