Beyond Oscillations: Atypical Responses from a Real-World Solar PV Plant

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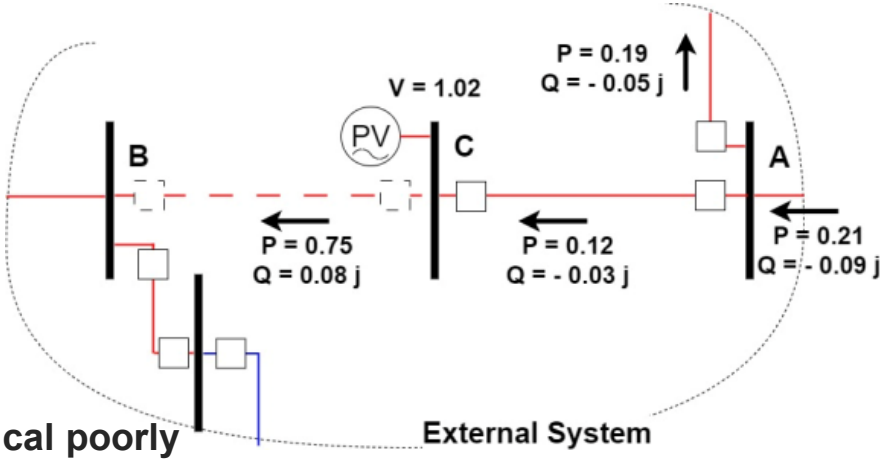
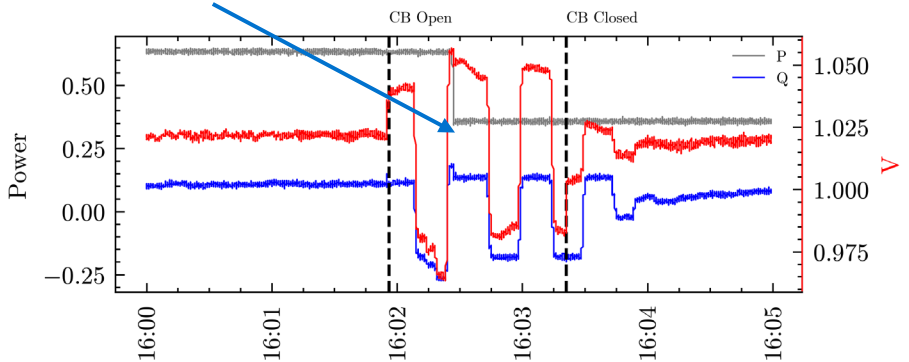
Study System

- Substation **C** has a 75 MW solar
- 115 kV network
  - C-B is the shortest path to 230 kV network
- Removing **C-B** triggered an atypical response from solar plant **C**
- Measurement device
  - DFR at C, $4800 \rightarrow 960 \rightarrow PMU\ (60\ Hz) \rightarrow_{downsample} 30\ Hz$



Atypical poorly damped response



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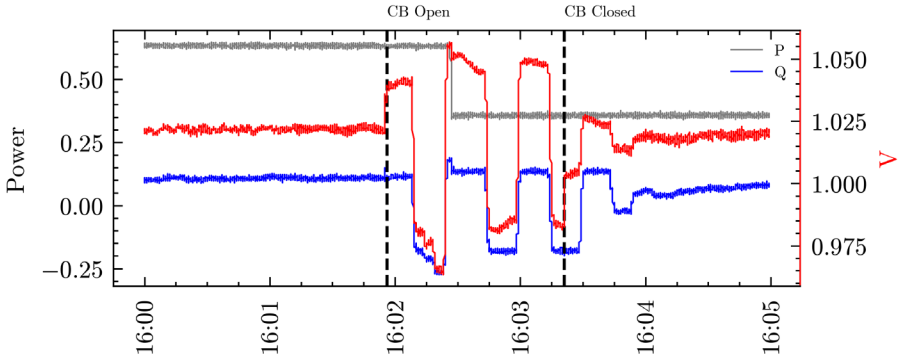
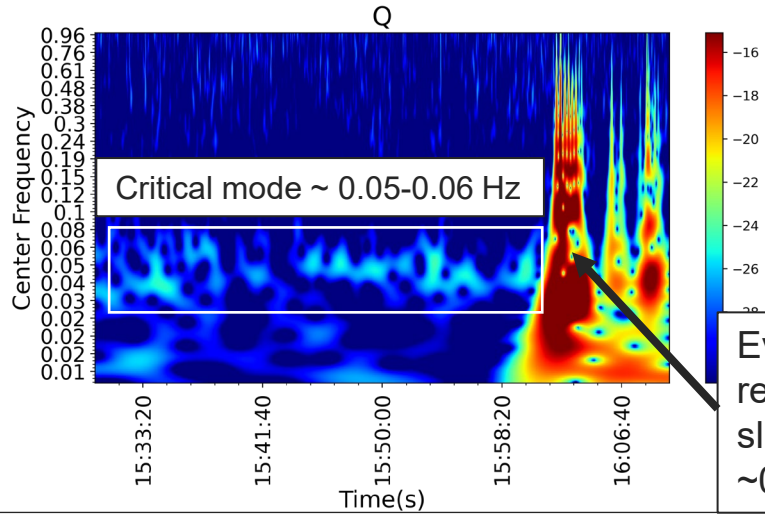
Event

- Line **C-B** was taken out of service, triggering slow, sustained, square like voltage magnitude swings of +- 3%
- Lasted for ~100 seconds, vanished once **C-B** connected
- Emerge from solar plant at C
- Only observed in Q
- **Goal:** Understanding the mechanism behind observed behavior



Atypical Swings in Voltage



Event response slightly slower ~0.03 Hz

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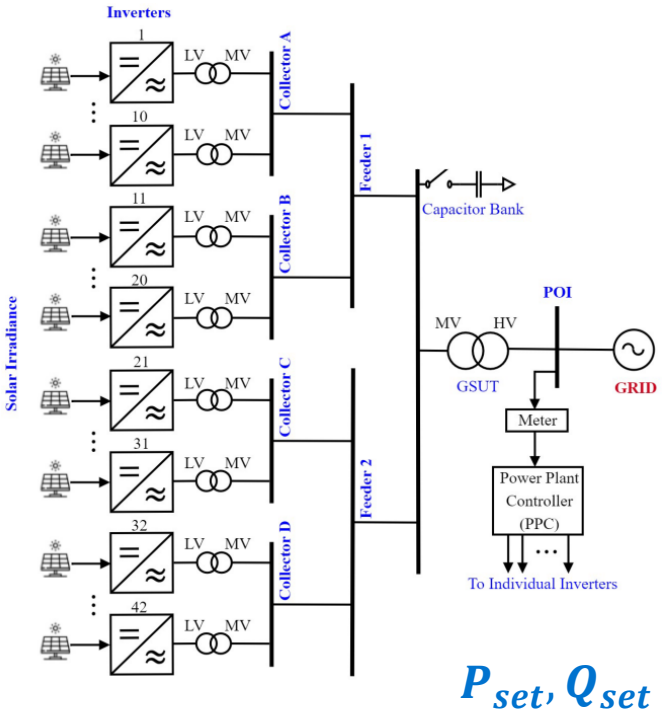
Power Plant Control Setup



P_{set}, Q_{set}

1 Control Mode

- P_{ref}
- $MPPT$

P Control Logic

PID + saturation

P_{set}

3 Control Modes

- V_{ref}
- Q_{ref}
- PF_{ref}

Q Control Logic

3 x PID (one per mode)
PF clamped to 0.95 lag/lead

Q_{set}

Inverter Control

Controller Arrangement at Solar

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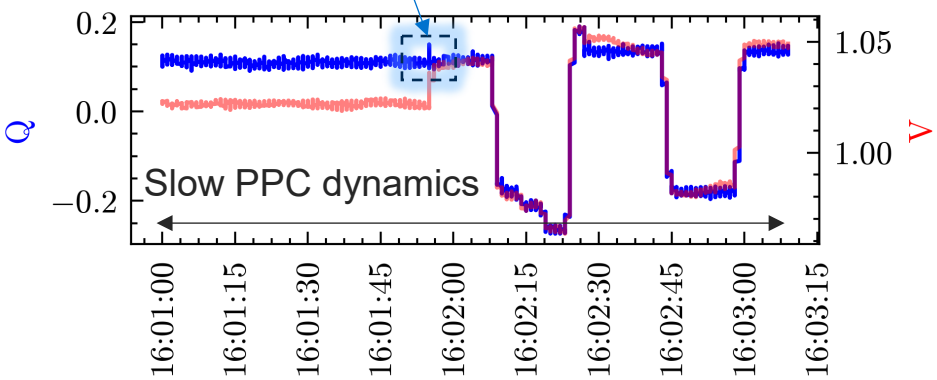
Identifying the Culprit

Q immediately returns to pre-event value (fast stable inverter dynamics)

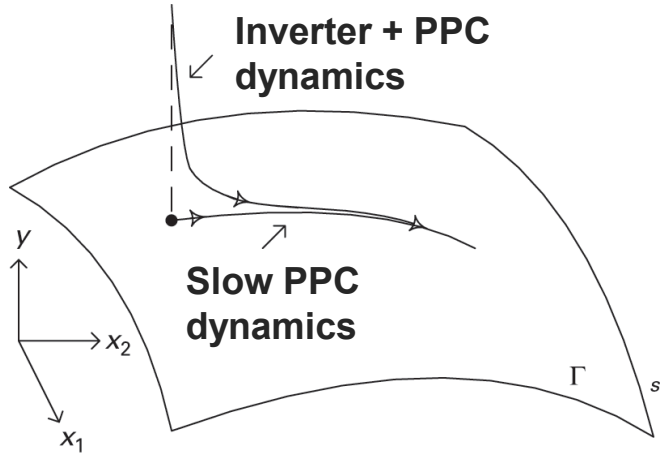


PPC or Inverter ?

Can be modeled as a two-time scale system

$$Slow\ PPC\ \dot{x} = f(x,y)$$

$$Fast\ Inverter\ \dot{y} = \frac{g(x,y)}{\epsilon} \approx \begin{matrix} \dot{x} = f(x,y) \\ 0 = g(x,y) \end{matrix}$$



Two Time Scale System

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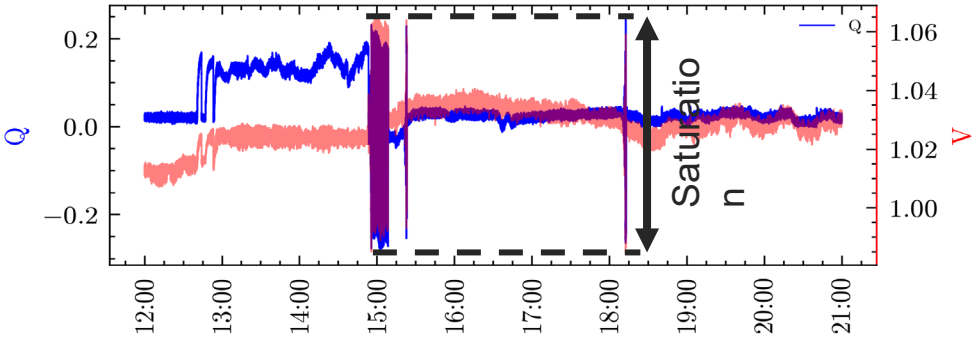
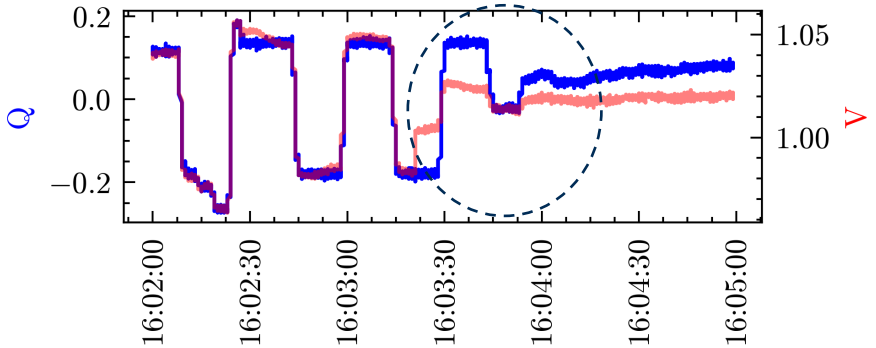
Why Square Like Characteristic Dynamics?

Usually stems from nonlinearities such as controller saturation



Unstable Behavior 3 Months Prior

Does not explain the shape during ring down



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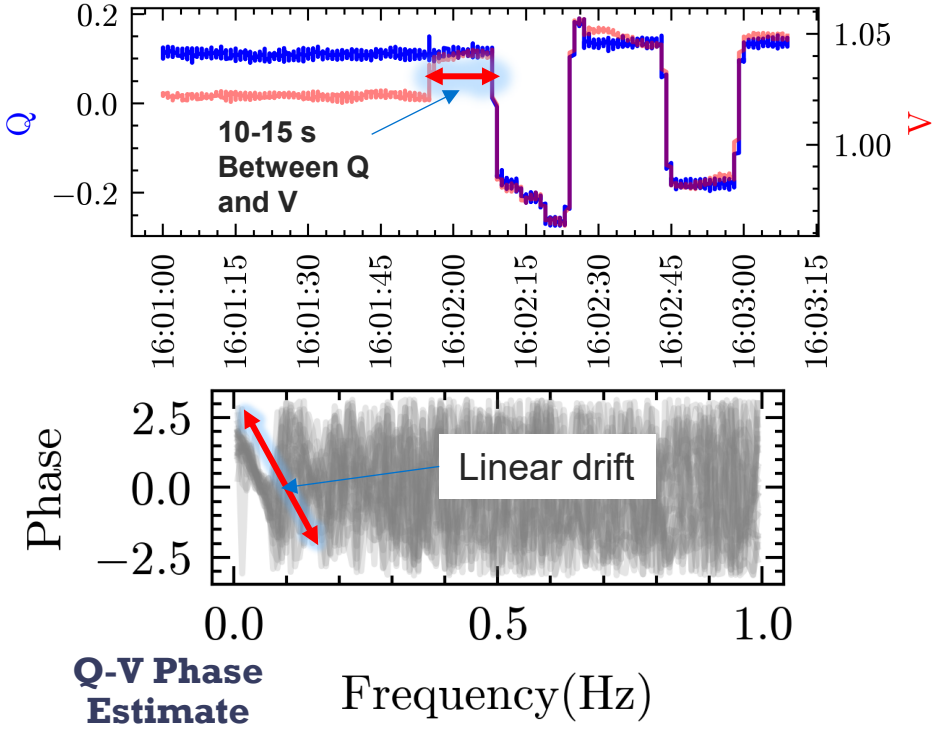
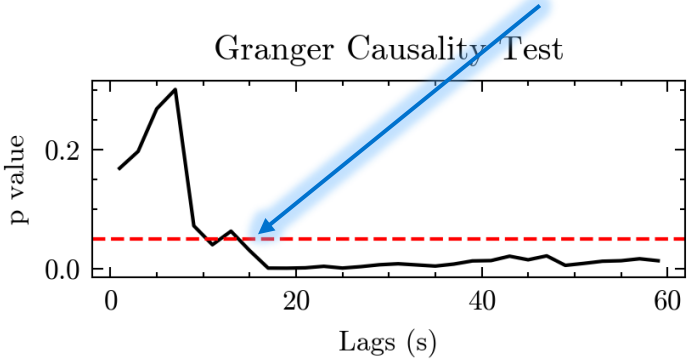
Large Feedback Delays?



Significance of $V_{t-T} \forall T \geq 10$ in explaining Q_t



$$H_0: y_t = \sum_k y_{t-k} + \epsilon_t$$

$$H_1(n): y_t = \sum_k y_{t-k} + \sum_{j=1}^{n} u_{t-j} + \epsilon_t$$

Iteratively testing H_0 vs $H_1(n)$

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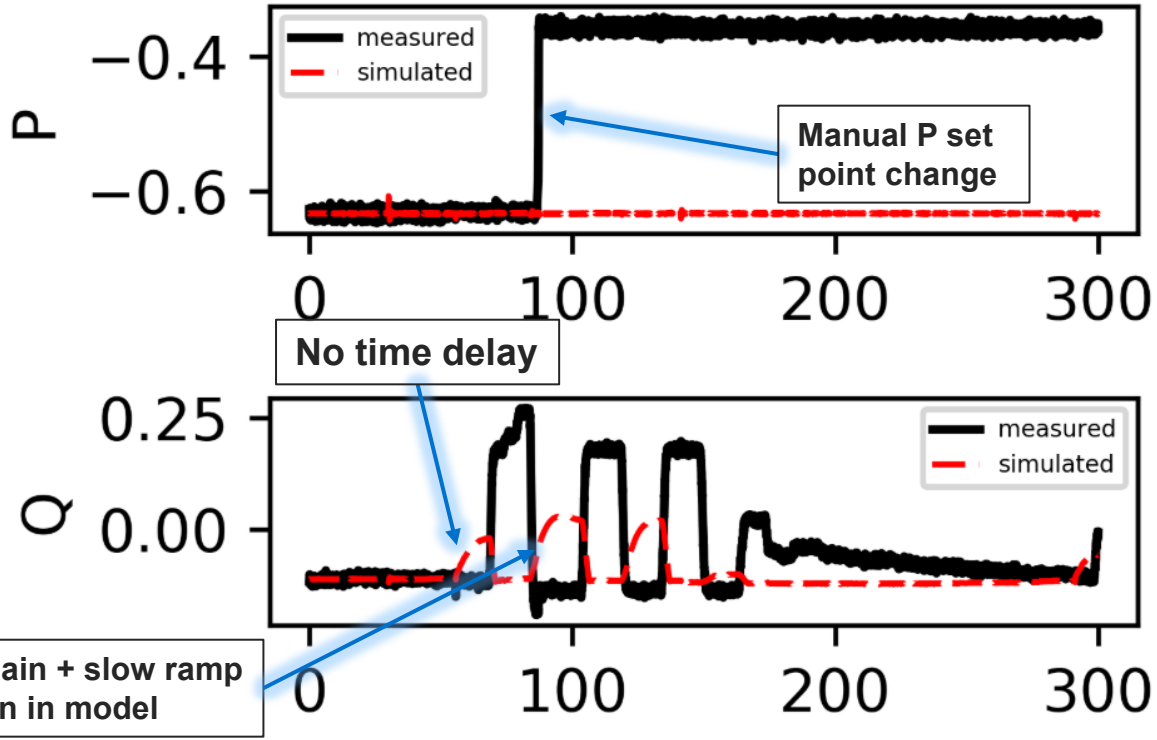
Response from PSS\E Model (What's Missing?)

- Assumed that models can be relied on to explain dynamics
- Generic model inverter models used
  - Should not matter as long as fast and stable
- PPC manufacturer did not provide own model
  - REPCA1 used instead



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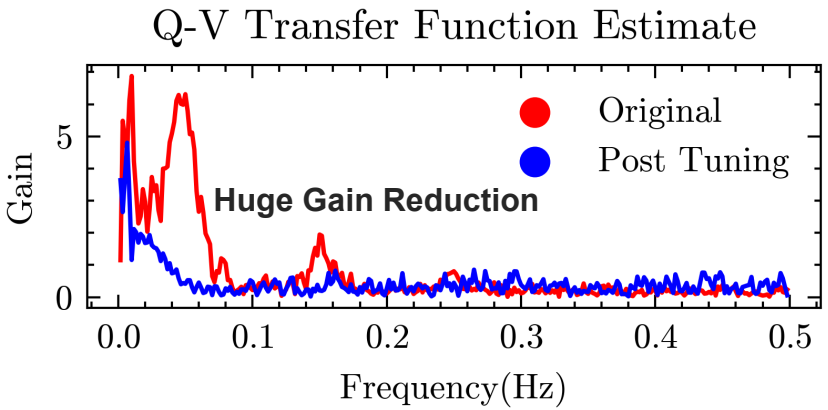
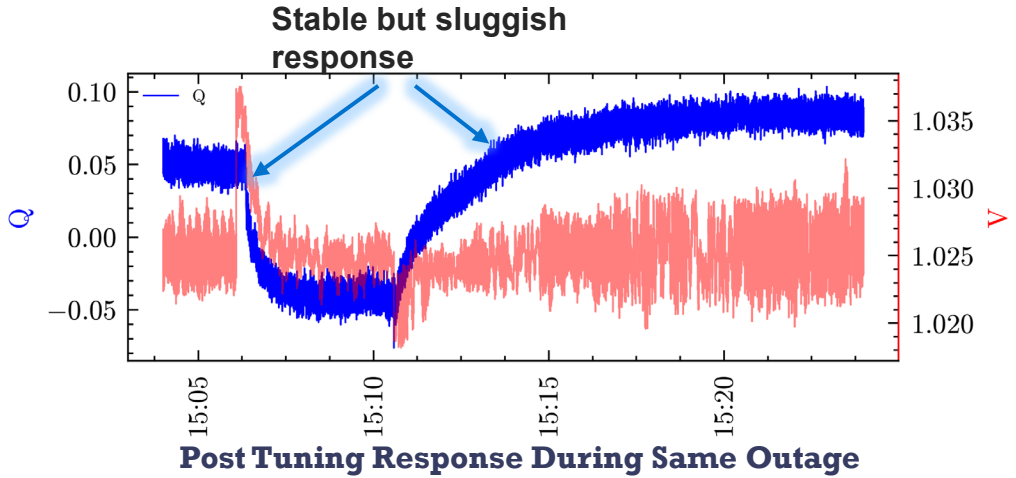
Tuning 3 Months Later (Stability vs Performance)

- Plant stability issues are being dealt with by taking the asset offline until fixed
- No performance requirements set for controllers
- **Result:** Debilitating controllers in favor of stability





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Takeaways

- Today we reviewed the analysis of poorly damped square wave type MVAR response from solar plant during outage
- We observed a stable inverter and tracking PPC setpoint
  - We regularly see PPC stability issues during weakened grid conditions
- Anomalous behavior can be explained by large time delays 10-15 seconds
- Controller gains scaled down in favor of stability, at the cost of performance
  - There is no set process to track controller performance. This is an item to address.
- Models today often do not explain observed dynamics behavior
  - Improperly set gains + no provision for delays

Other Events from Dominion

[A] C. Mishra, L. Vanfretti, J. Delaree and K. D. Jones, "Analyzing a Non-Sinusoidal Response from a Real-World Solar PV," in IEEE Transactions on Power Systems, vol. 39, no. 2, pp. 4771-4774, March 2024, doi: 10.1109/TPWRS.2024.3350377. Author's copy: here

[B] C. Mishra, L. Vanfretti, M. Baldwin, J. de la Ree Jr., and K. D. Jones, "Analysis of Generator Forced Oscillations during MOD 25 Testing Exploiting Wavelets," Hawaii International Conference on System Sciences (HICSS), Hilton Hawaiian Village Waikiki, January 3-6, 2024. Author's copy: here

[C] C. Mishra, L. Vanfretti, D. Yang, C. Wang, X. Xu, K.D. Jones and M.R. Gardner, "Analysis of STATCOM Oscillations using Ambient Synchrophasor Data in Dominion Energy," 2022 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT 2022), Feb. 21-24, 2022, Washington D.C., USA. Author's copy: here

[D] C. Wang, L. Vanfretti, C. Mishra, K.D. Jones, R.M. Gardener, "Identifying Oscillations Injected by Inverter-Based Solar Energy Sources," 2022 IEEE Power & Energy Society General Meeting, 17–21 July 2022, Denver, Colorado. Author's copy: here

[E] X. Xu, C. Mishra, L. Vanfretti, C. Wang, K.D. Jones, J. Brian Starling, and R. M. Gardner, "Tracking Periodic Voltage Sags via Synchrophasor Data in a Geographically Bounded Service Territory," 2023 IEEE Grid Edge Technologies Conference & Exposition, April 10-13, 2023, San Diego, California, USA. Author's copy: here

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Thank You
Questions?

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