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A Fast Quasi-Static Time Series (QSTS) Simulation Method for PV Impact Studies Using Voltage Sensitivities of Controllable Elements

Xiaochen Zhang[1], Santiago Grijalva[1], Matthew J. Reno[2]

Jeremiah Deboever[1], Robert J. Broderick[2]

1. Georgia Institute of Technology
2. Sandia National Lab

Outline

- Introduction of quasi-static time series (QSTS) simulation
- Fast QSTS Simulation Method
  - Voltage Sensitivity Models
  - The “Plane Model” for System Controllers
  - Multiple Load Profiles and Controllers
  - Parameter Estimation
  - Model Results & Summary

Quasi-static Time Series Analysis

- What is quasi-static time series (QSTS) simulation?
  - A simulation solves power flow chronologically through time.
  - Each solution, uses the previous power flow results
  - Consider time delays and thresholds of all the controllers
- Why do we need to run QSTS simulation?
  - Yearlong high-resolution QSTS simulations are required to analyze the impact of PV integrations for seasonal trends and the highly variable PV outputs.
- Why do we need 1-second resolution QSTS simulation?
  - Only second level resolution can capture the collaboration and possible oscillations among system controllers.
  - Yearlong 1-second resolution will result in solving 31 million power flows.

Quasi-static Time Series Analysis

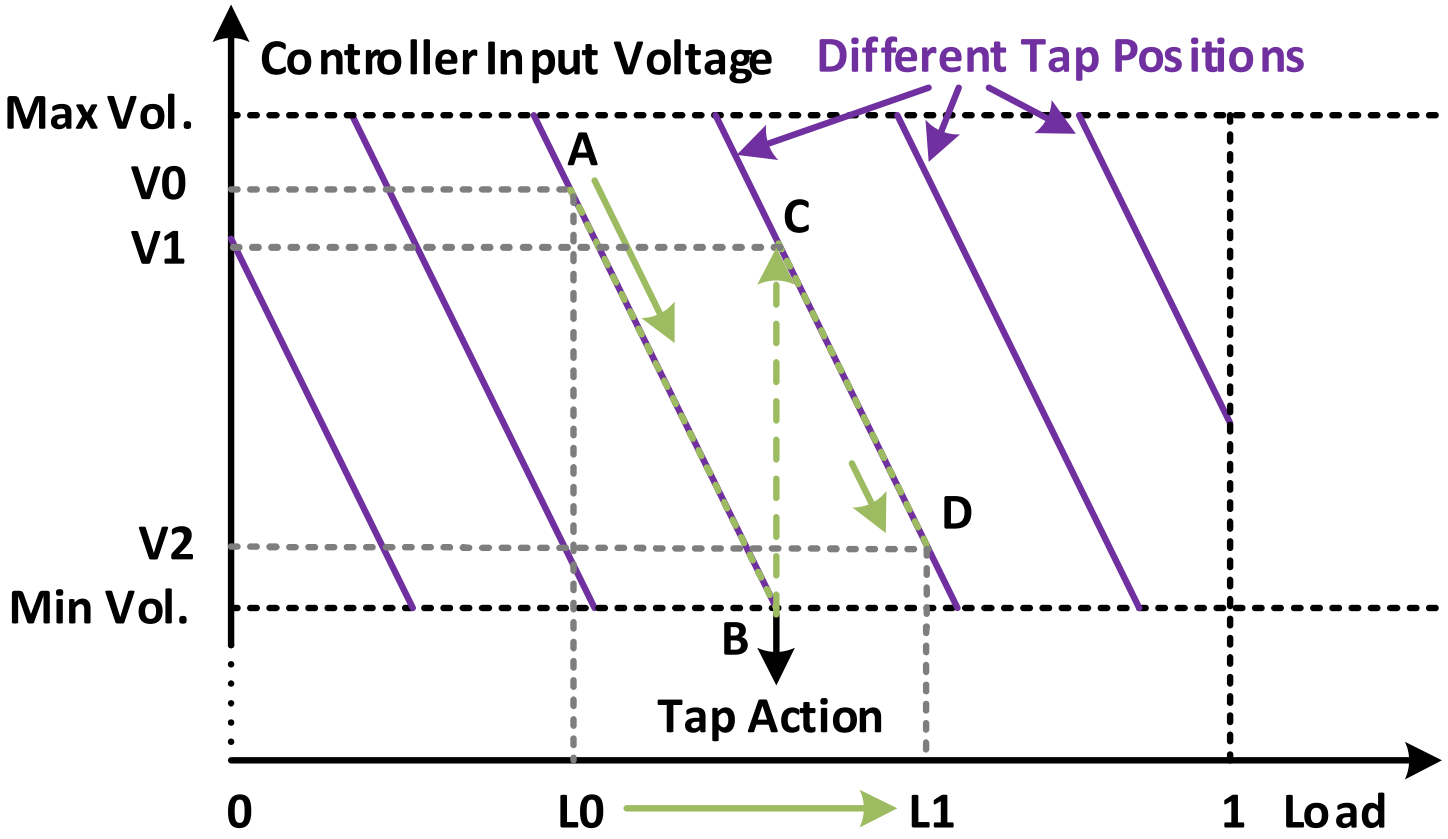
- Why QSTS is not widely applied?
  - The computational time for running yearlong high-resolution QSTS simulations takes 10 to 120 hours for realistic-sized distribution feeders.
- Why QSTS is slow?
  - Although each power flow takes a fraction of a second to solve, multiply that with 31 million solves of a year scaling up the time.
- Why fast QSTS is difficult?
  - Time dependency of the time-series simulation.
  - Interactions of system controllers.
  - Presence of multiple valid power flow solutions.

Key to fast QSTS is predicting controller events.

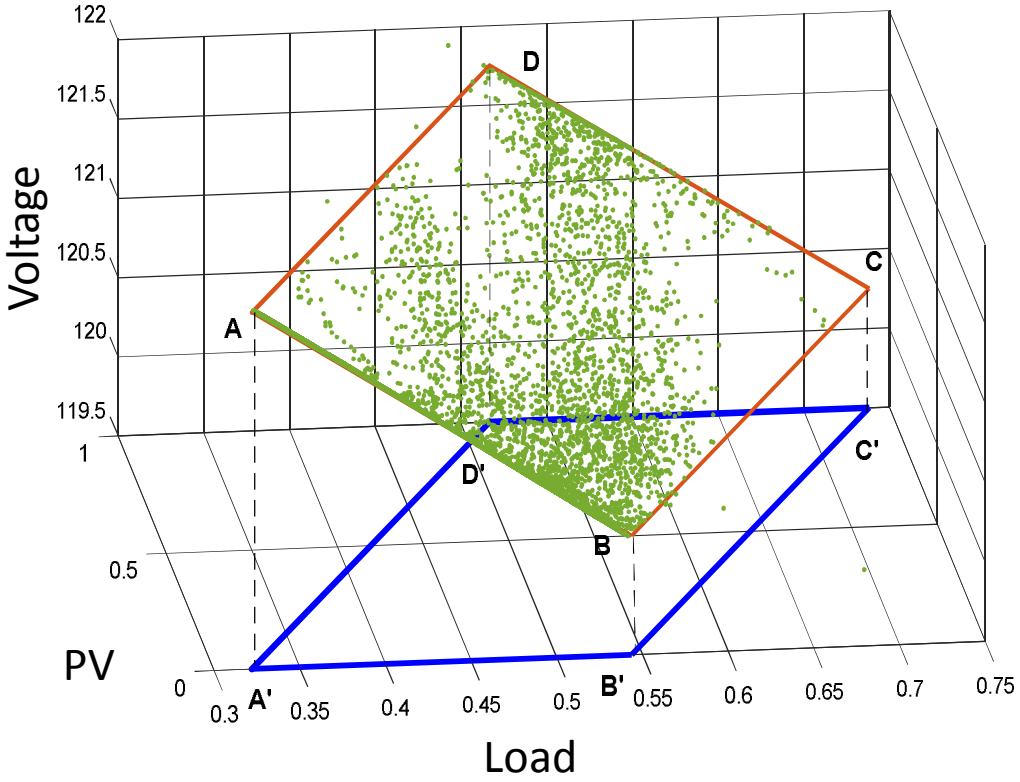
Solution: Event-based Simulation

- Objective:
  - Use voltage sensitivity to predict system events.

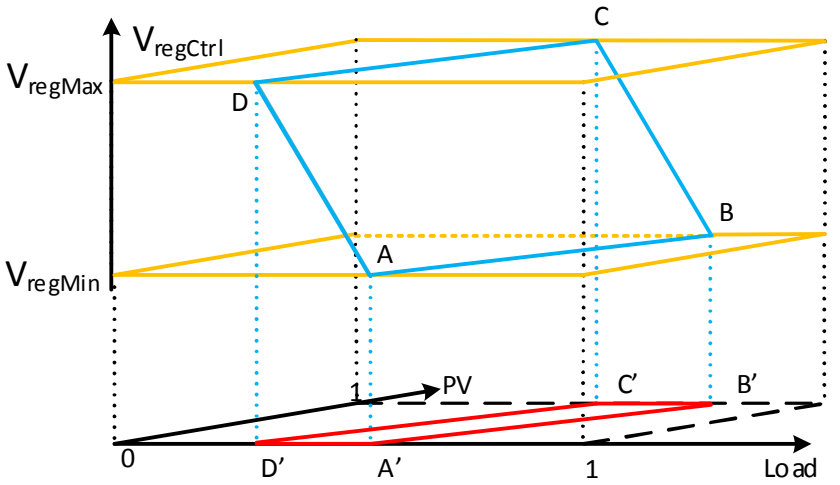
For a system with one regulator and one load profile.



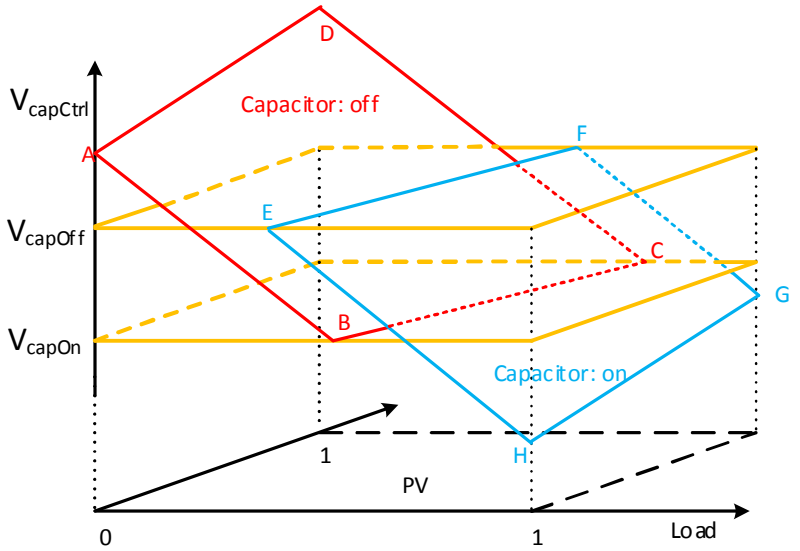
Multi-load Profiles



- Add another load profile (PV output)
- Multiple load profiles → Hyper Plane
- For purpose of predicting system events, we project the red plane down to form a decision boundary

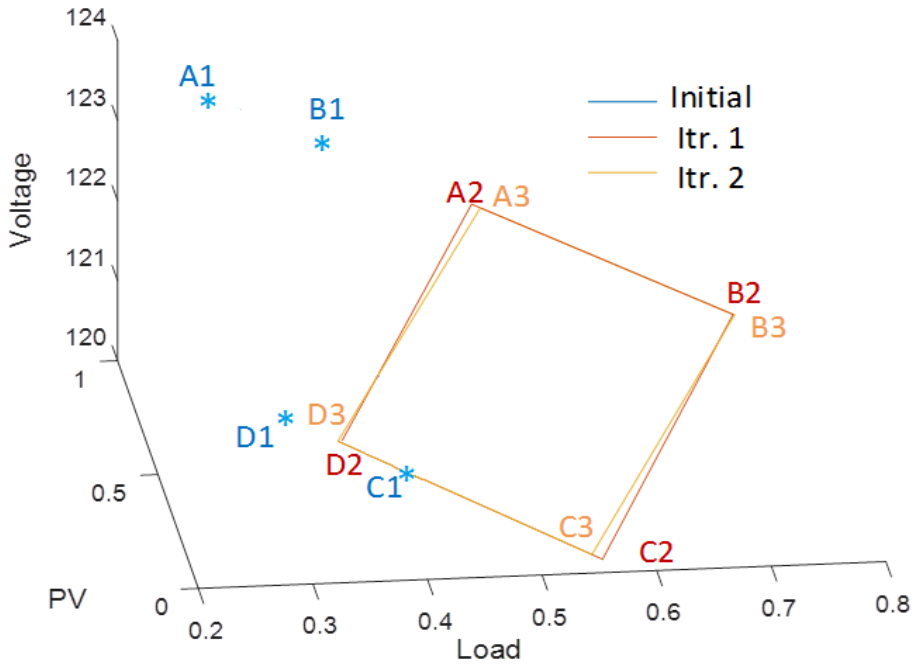


Regulator Model

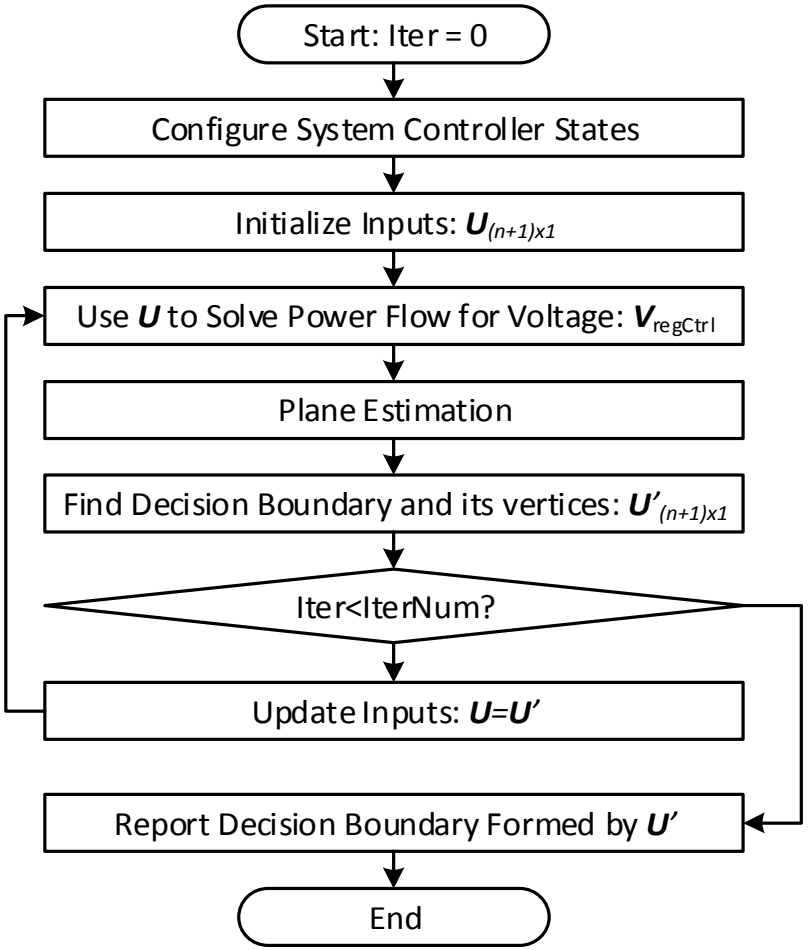


Capacitor Model

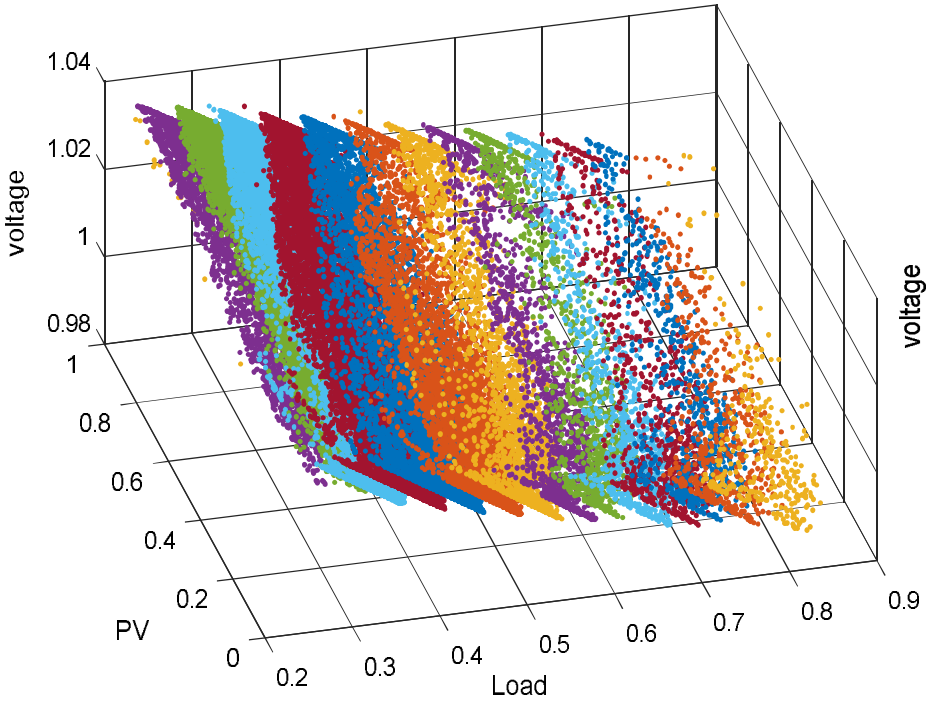
Iterative Method for Decision Boundary Estimation

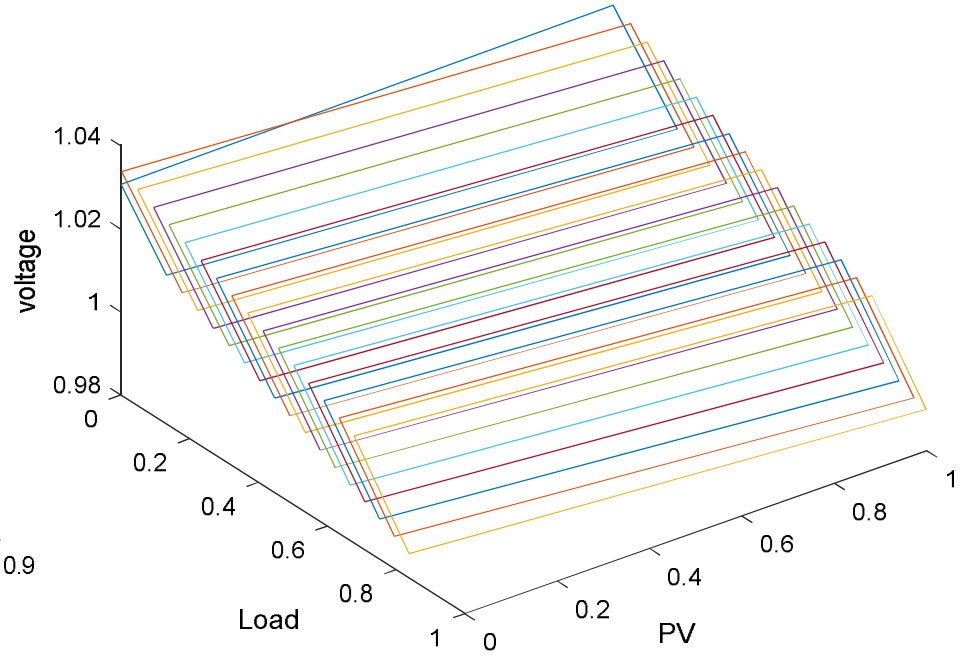


- We estimate the plane model by solving a couple of power flows
- An iterative method is used to improve parameter estimation accuracy



Estimated Plane Model Vs. Real Data

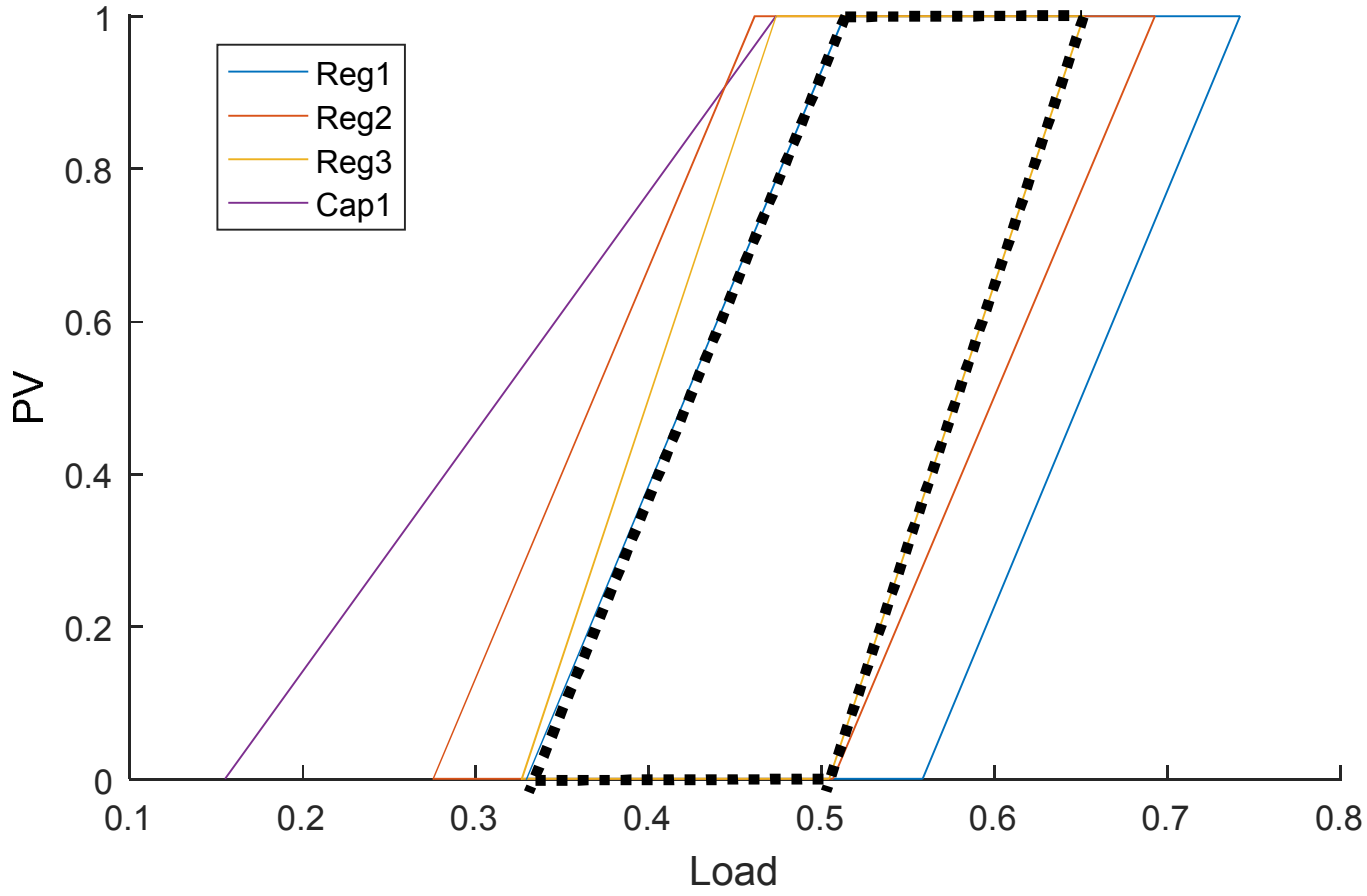




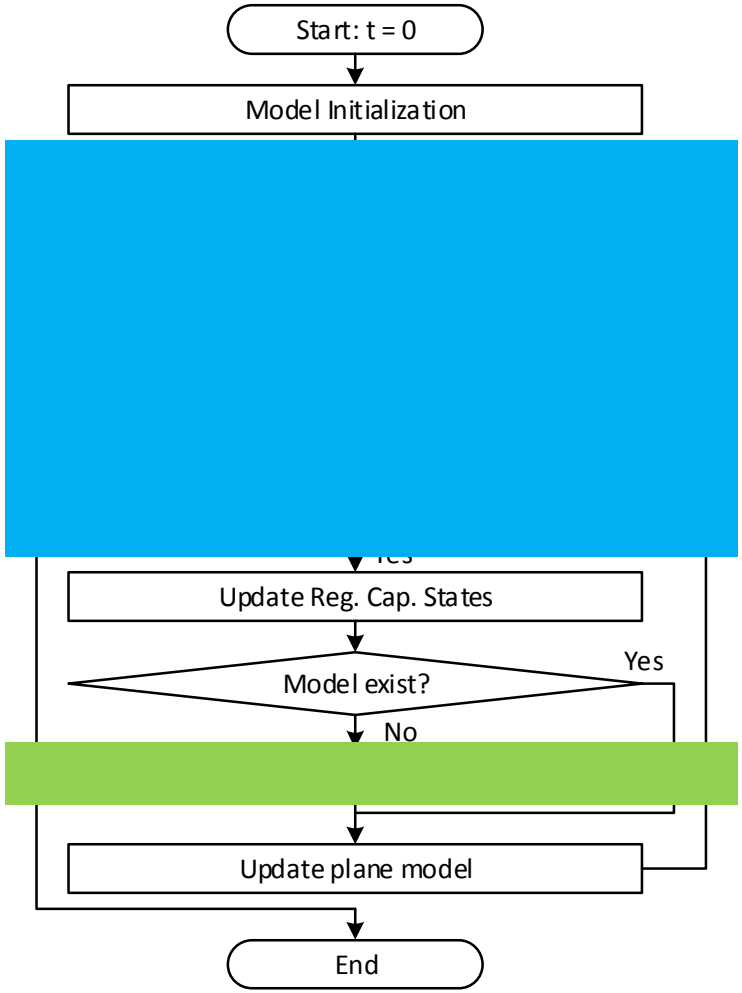
- Bus voltage log from brute force QSTS simulation.
- 31 million points, and each point stands for a power flow solution for the bus.

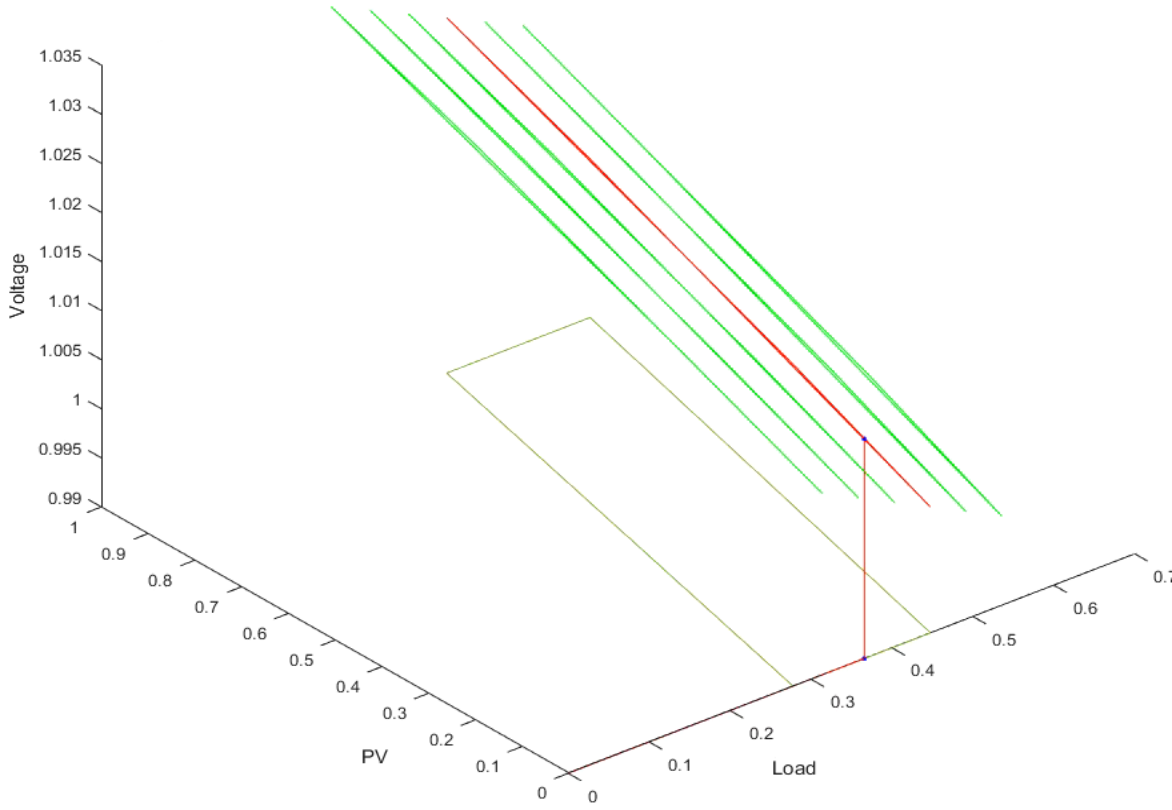
- We derived a plane model for a system regulator
- Each plane takes 4 power flow to determine.

Multiple Controllers



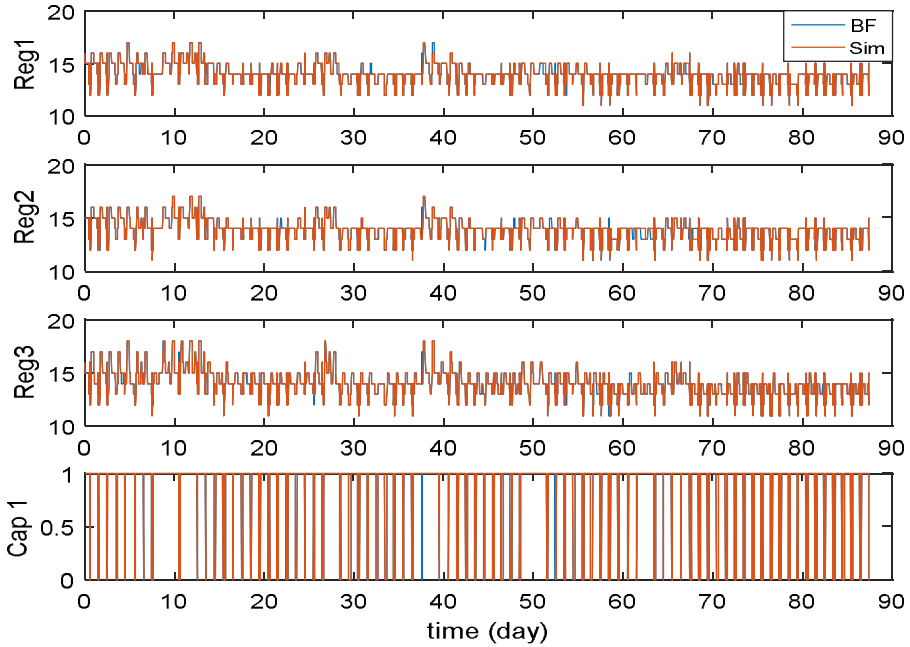
Flow Chart


Start: t = 0
Model Initialization
Update Reg. Cap. States
Model exist?
Yes
No
Update plane model
End


Voltage
1.035
1.03
1.025
1.02
1.015
1.01
1.005
1
0.995
0.99
PV
Load

Event-based Simulation Results

- The event-based simulation is extremely fast.
- We reduce the power flow solves from 31 million to less than 800.
- The algorithm accurately captures behavior of all system controllers.



Num. of Iterations	Reg. Avg. Err (%)	Cap. Avg. Err (%)	Comp. Time (sec)	Comp. Time Reduction (%)
0	3.22	2.35	6.34	99.21
1	2.24	-5.19	6.47	99.20
2	1.91	-4.94	6.57	99.19
3	1.91	-4.94	6.75	99.16
4	1.91	-4.94	6.96	99.14

Summary

- What is the event-based simulation?
  - The proposed event-based simulation method to speed up QSTS simulation by utilizing a voltage sensitivity model.
  - The voltage sensitivity model, aka the “plane model”, can accurately capture the control logics of system controllers.
- Why is the proposed method important?
  - This method makes yearlong 1-second QSTS simulation possible and affordable for wide applications, especially PV plug-in analysis.
- Characteristics of the proposed method
  - Extremely fast and efficient.
  - Can be used to track various QSTS indices (tap actions, bus voltage...)
  - The computational time increases as more load profiles and more controllers are added to the system.

Acknowledgment

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Questions?

Xiaochen Zhang
x.zhang@gatech.edu

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