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Voltage Control Performance Evaluation using Synchrophasor Data January 2020

Joe H. Chow, Christoph Lackner
Rensselaer Polytechnic Institute
Troy, NY, USA

Felipe Wilches-Bernal
Sandia National Laboratories
Albuquerque, NM, USA

Atena Darvishi
New York Power Authority
White Plains, NY, USA

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Overview

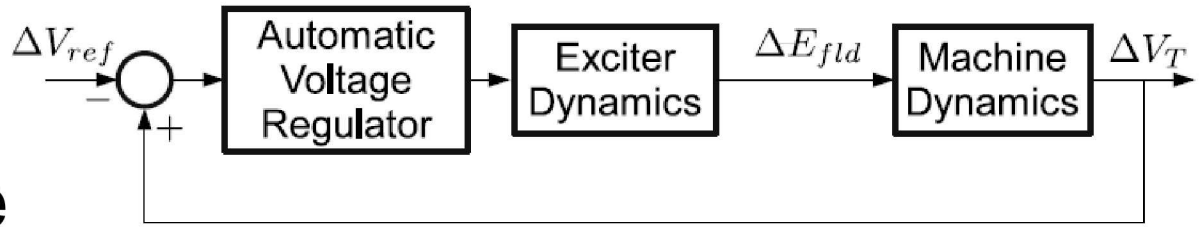
- Motivation
- Voltage Regulation
- Proposed Algorithm
- Performance Evaluation Results
  - During Disturbances
  - During Ambient Operation

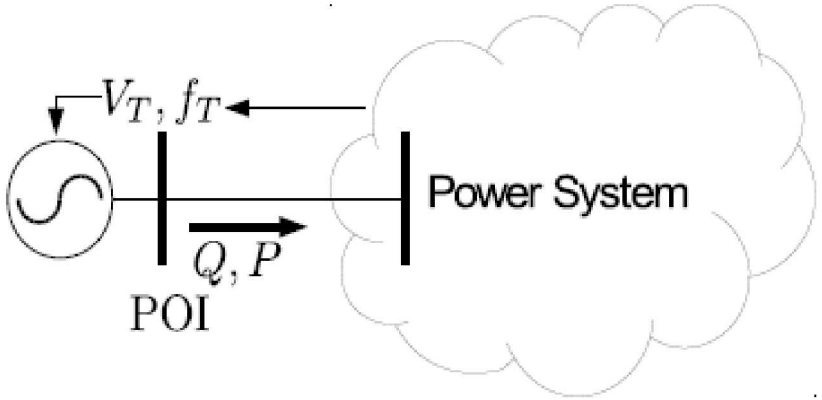
Motivations

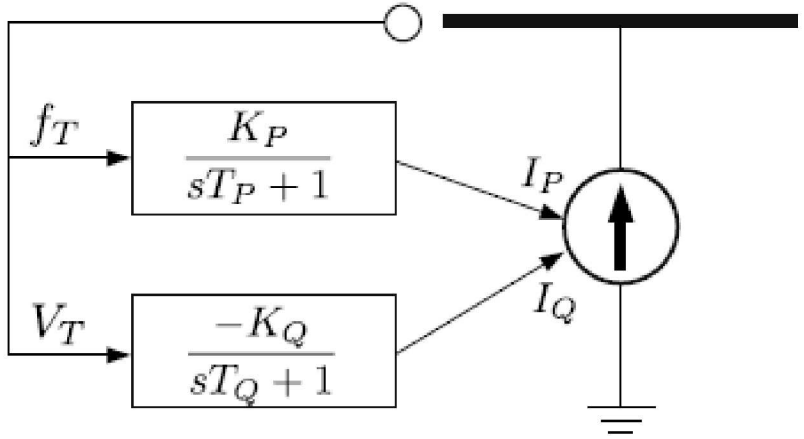
- Current approach:
  - Use PMU data for model parameter identification and verification
  - Difficulties:
    - The small time constants associated with machine subtransient circuits are not readily identifiable (requires higher PMU sampling rate)
    - Some equipment (such as wind turbines) have multiple control modes and it may not be clear as to which mode is in operation
    - Parameter identification tends to be a manual tuning process (assisted by power system simulation software with playback capability)

Voltage Regulation

- Voltage Regulation Loop creates response in reactive power injection based on change in terminal voltage
- Some converter-based equipment models can be separated into active and reactive part

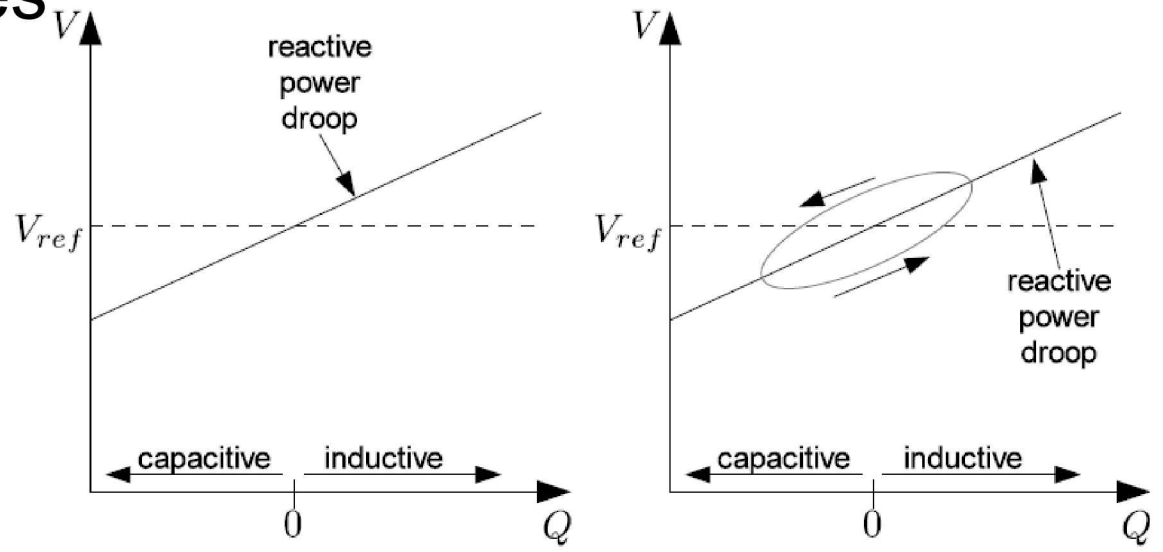




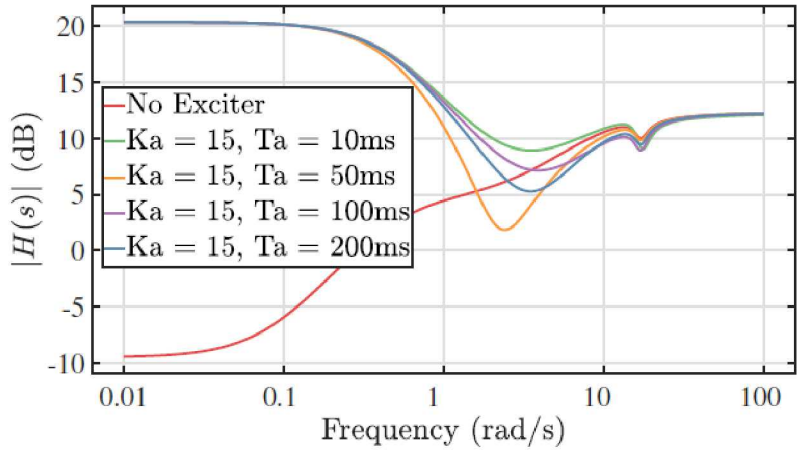


Voltage Regulation

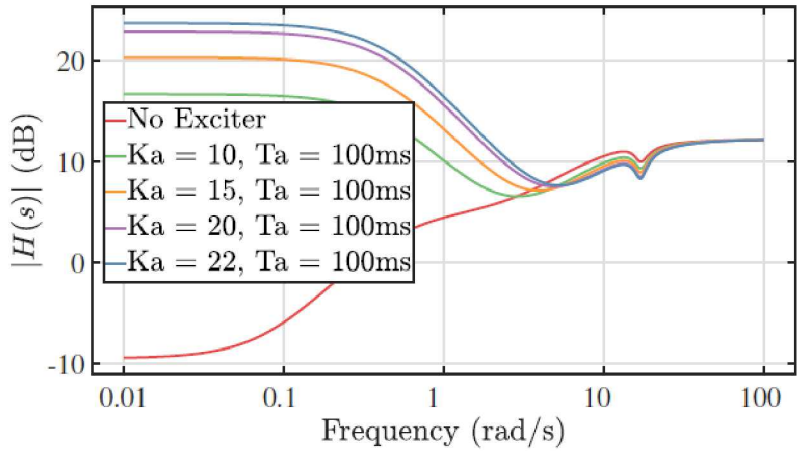
- A simplified mode can be used to estimate
  - Droop
  - Time constant
- Voltage vs Q plots show regulation
- Control parameters only effect model at lower frequencies



(a) Fast Regulation (b) Slow Regulation



(a) Effect of T_A



(b) Effect of K_A

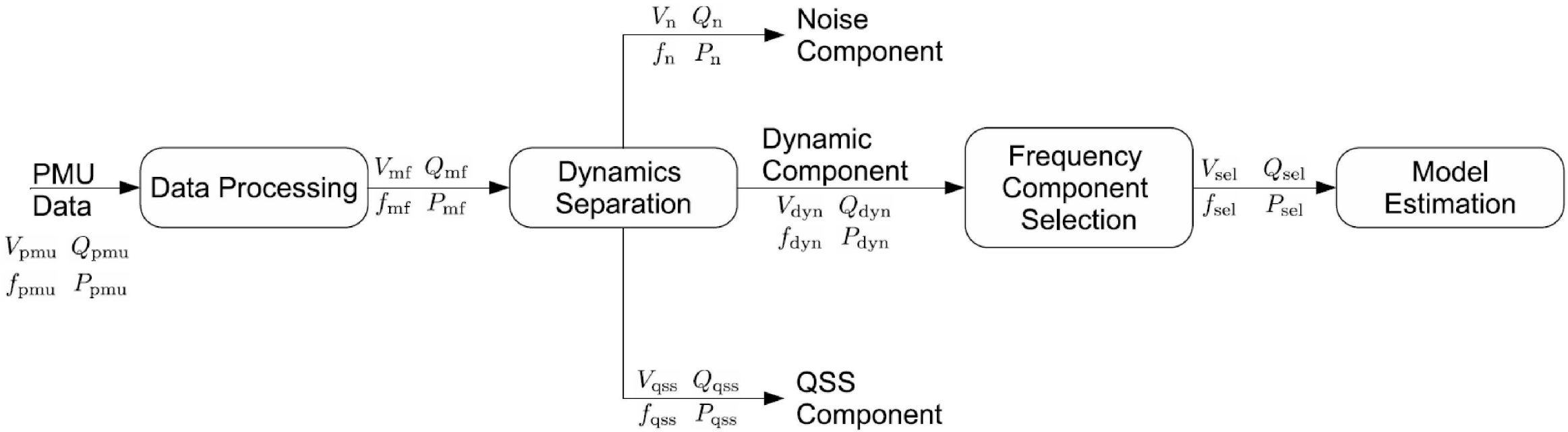
Voltage Regulation: Voltage vs Q plot

Raw data

Processed data

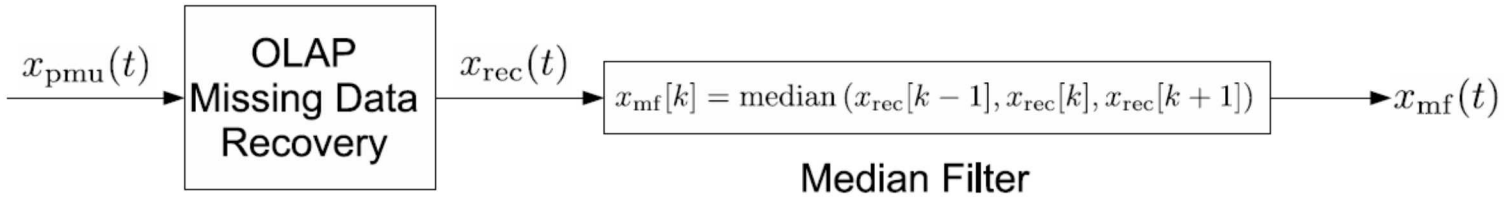
Proposed Algorithm

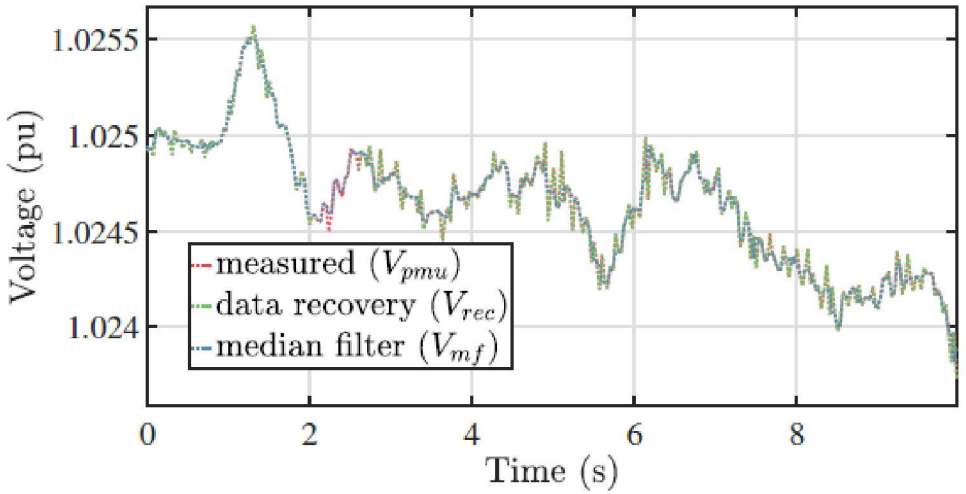
- Four-Stage Algorithm
  - Initial data processing
  - Dynamics separation
  - Frequency component selection
  - Dynamic model estimation



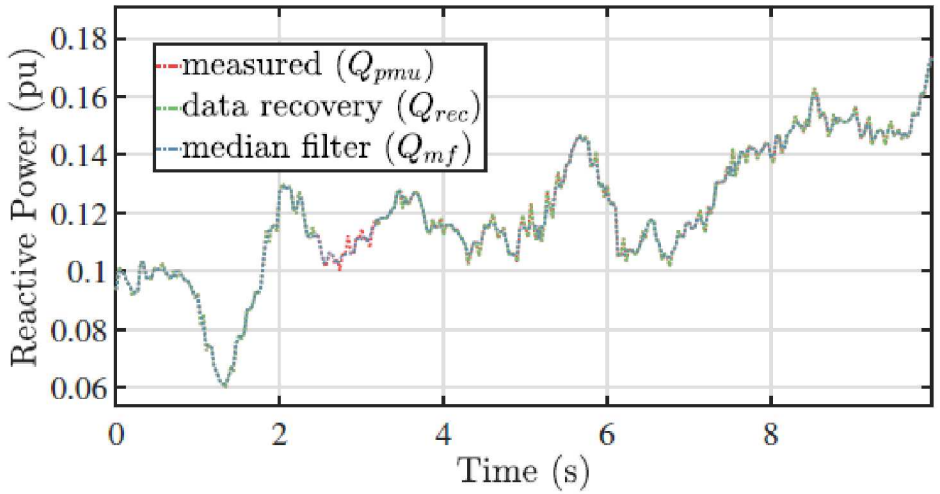
Initial Data Processing

- Removes bad data
- Replaces missing data
- Based on a 2nd order median-filter





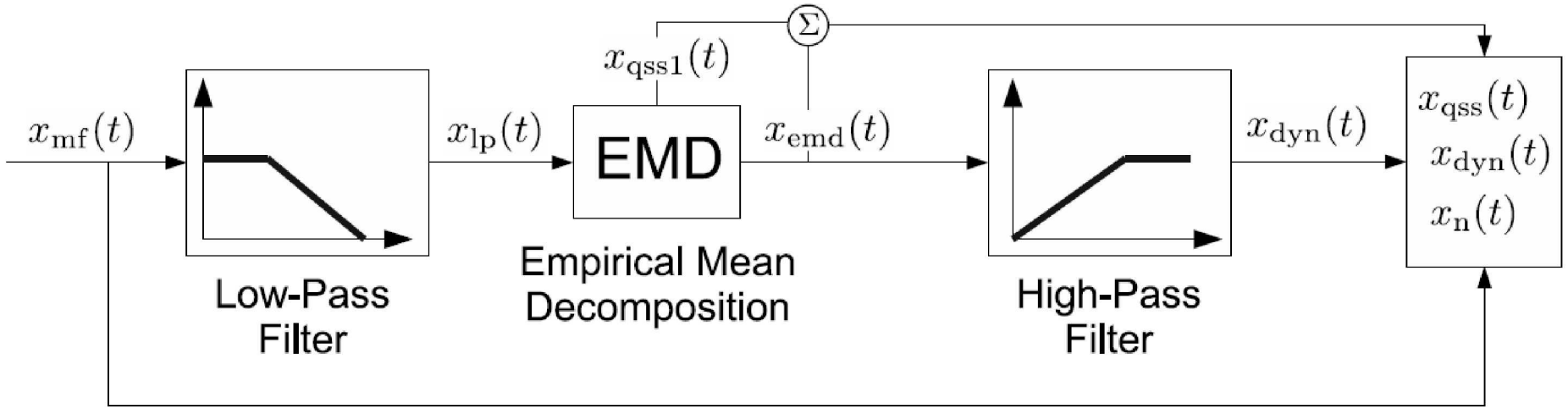
(a) Stage 1 V Signal



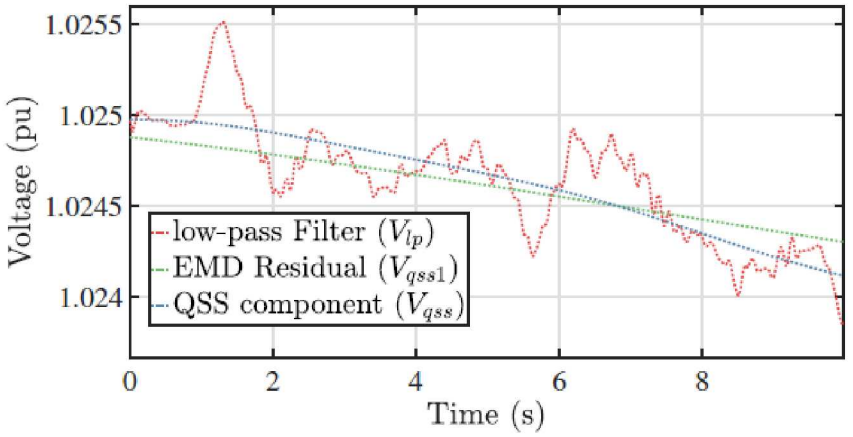
(b) Stage 1 Q Signal

Dynamics Separation

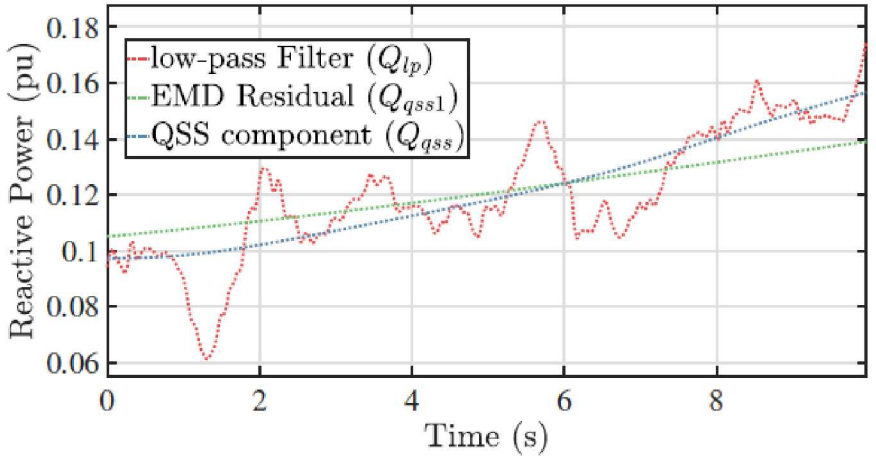
- Separates Signal into 3 components
  - Quasi-Steady-State (QSS)
    - Due to slow moving operating condition (e.g. load changes, AGC, dispatch)
  - Dynamic Component
    - Due to control systems
  - Noise
- Based on Empirical mean Decomposition (EMD) and linear filtering



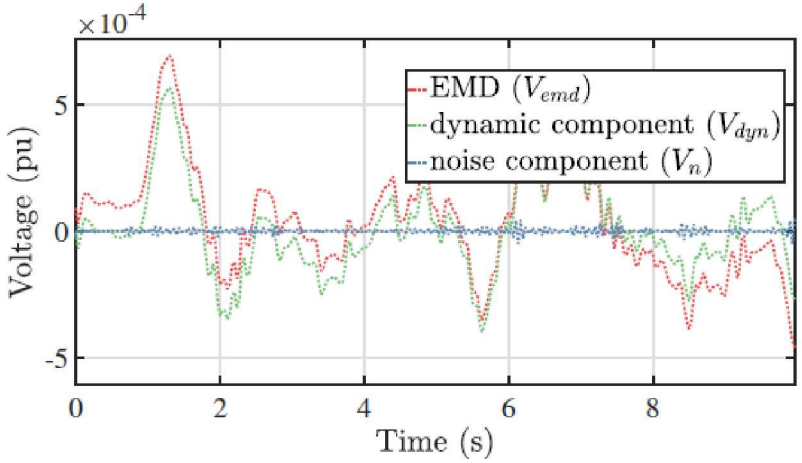
Dynamics Separation



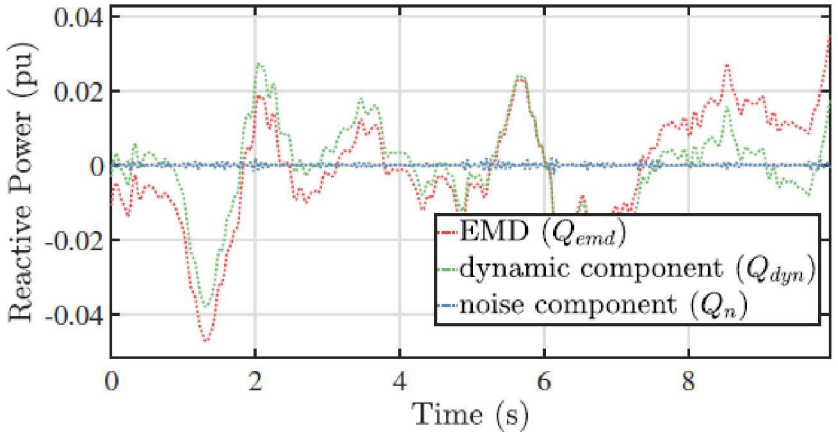
(c) Stage 2 V Signal



(d) Stage 2 Q Signal



(e) Stage 2 V Signal

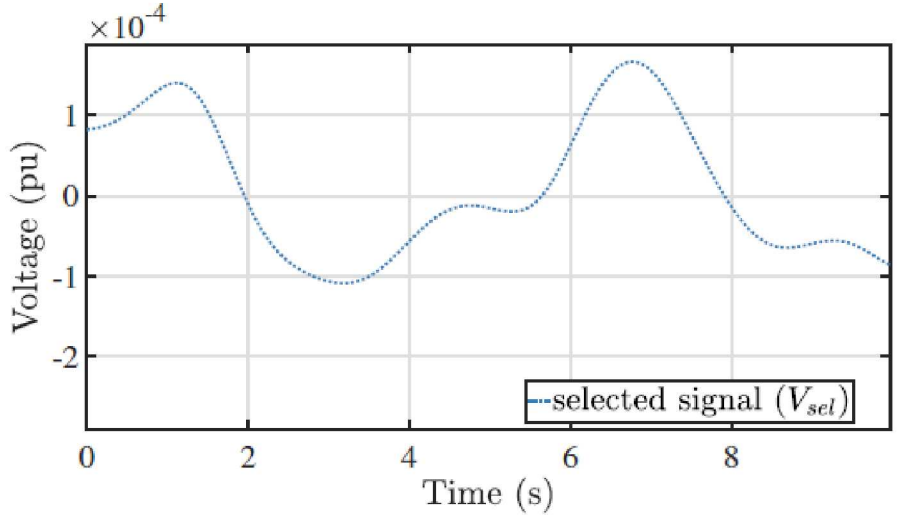


(f) Stage 2 Q Signal

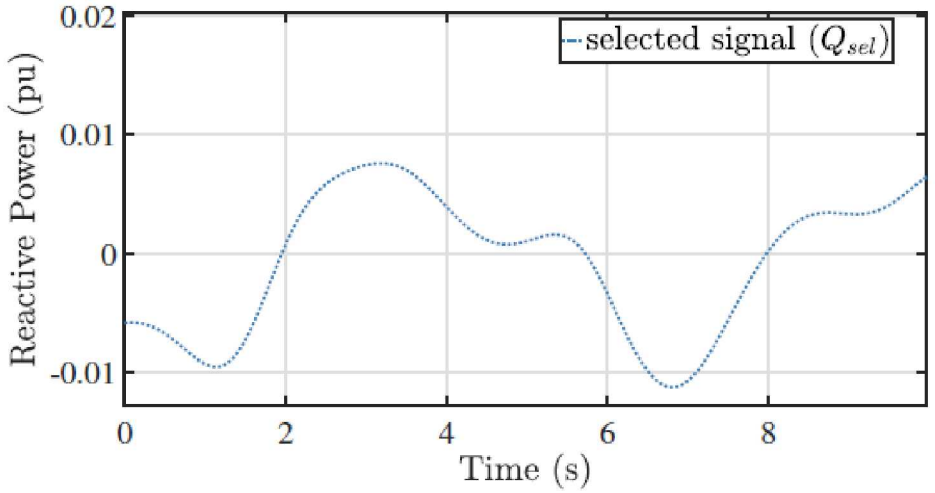
Frequency Component Selection and Model Estimation

- Frequency Component Selection
  - Based on linear filter
  - Only parts of the signal affected by the control parameters are used
- Model Estimation
  - Numerical Optimization of Mean Square Error (MSE)
  - Estimates Gain (Droop) and Time Constant

$$Q(s) = \frac{K_{QV}}{T_{QV}s + 1} V(s)$$



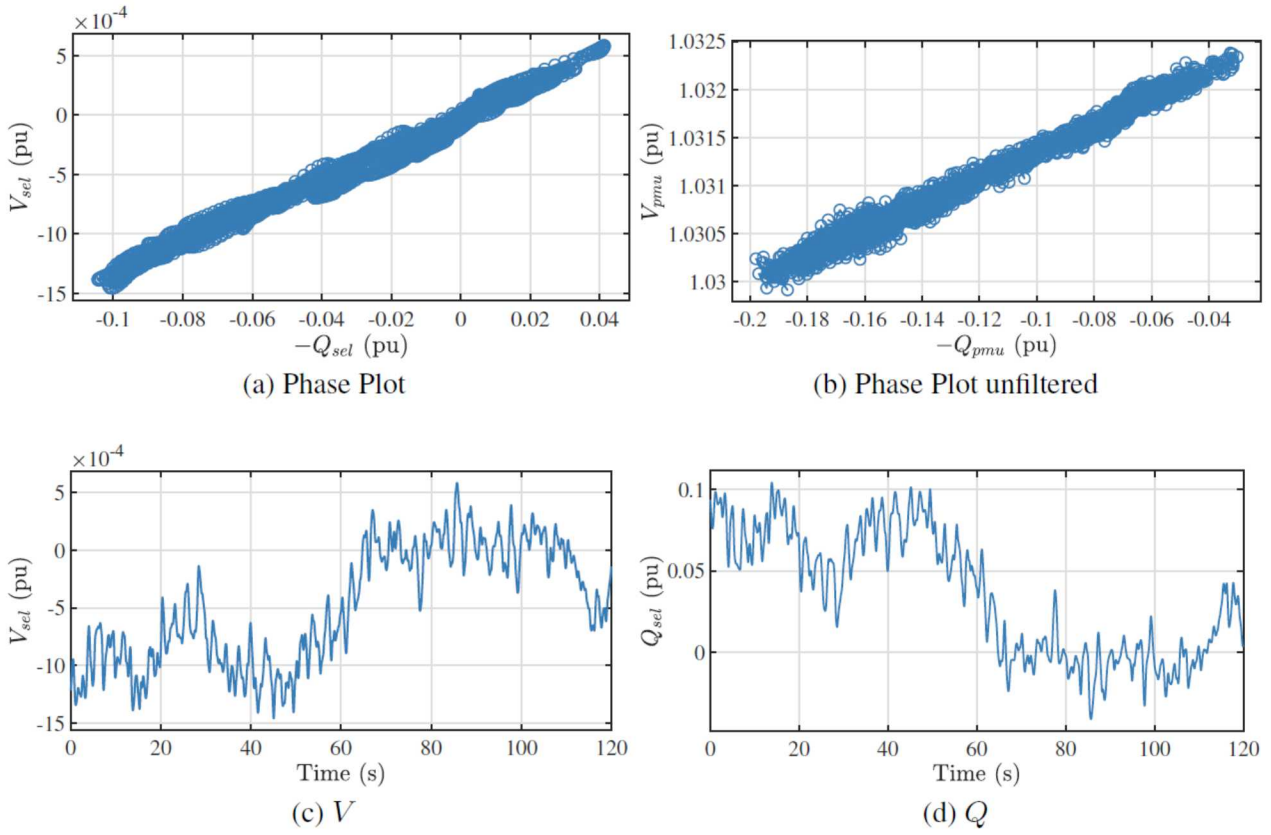
(g) Stage 3 V Signal



(h) Stage 3 Q Signal

STATCOM Performance Evaluation Results – Disturbance Data

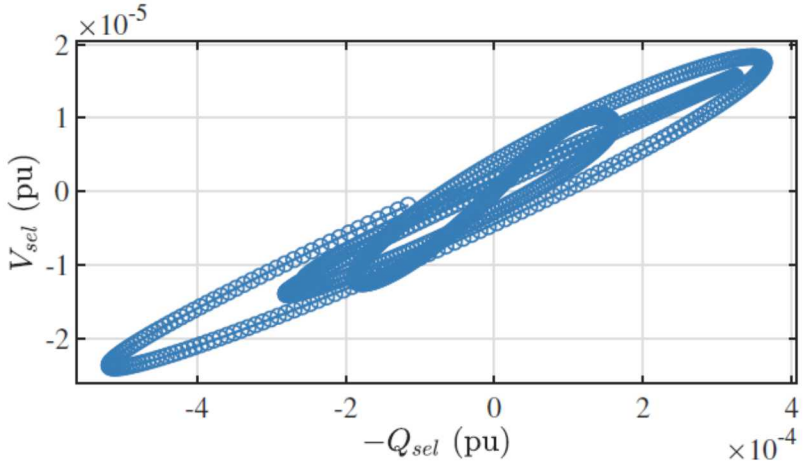
Event	Droop (%)	T (ms)
1	3.175	106.06
2	2.884	4.08
3	3.217	3.88
4	2.883	88.11
5	2.886	4.61
6	3.190	3.45
7	2.845	3.64
8	5.396	240.43
9	2.738	5.05
10	6.901	68.34
11	3.134	26.77
12	2.997	117.04
13	2.736	5.00
14	2.873	3.95
15	3.045	59.26
16	3.228	3.81



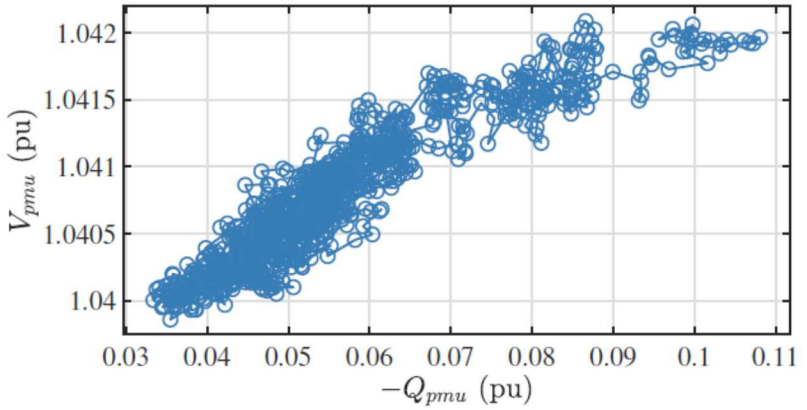
- Based on historical PMU data
- During Events 8 and 10 the STATCOM was partially out of service
- Droop confirmed by operator around 3%

Generator Performance Evaluation Results – Disturbance Data

Event	Droop (%)	T (ms)
1	30.533	1904.50
2	17.929	4761.68
3	18.917	4305.19
4	17.281	5086.73
5	16.770	506.72
6	10.170	491.00
7	10.799	1646.64
8	18.749	874.44



(a) Q-V

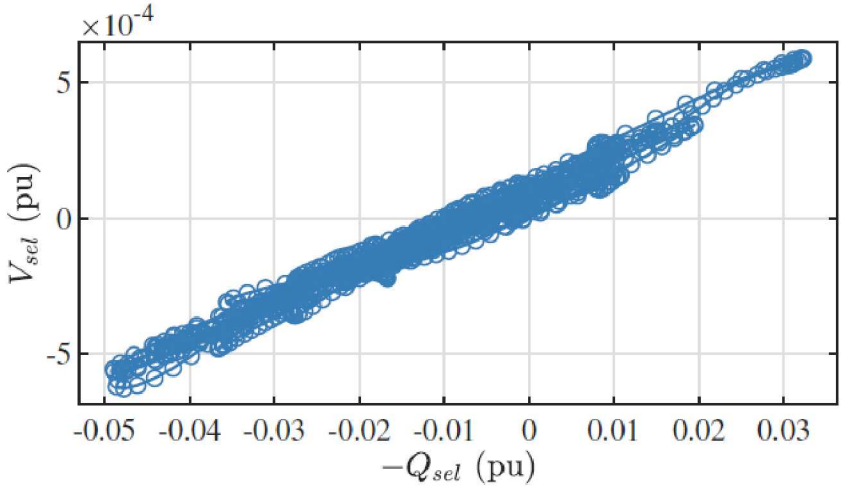


(b) Q-V unfiltered

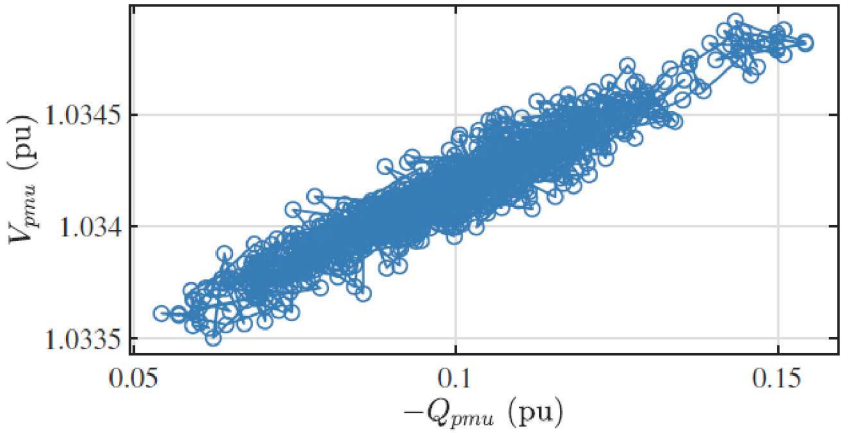
- Based on historical PMU data
- Hydraulic generating unit
- Confirmed droop around 13%

STATCOM Performance Evaluation Results - Ambient Data

Dataset	Droop (%)	T (ms)
1	2.652	20.28
2	2.847	42.89
3	3.469	27.91
4	3.809	3.55
5	3.212	4.04
6	3.589	1.53
7	2.844	3.54
8	7.128	32.64
9	2.836	24.00
10	4.697	0.76
11	2.005	4.70
12	3.123	47.30
13	2.620	4.01
14	3.489	2.58
15	2.768	3.80



(a) Q-V

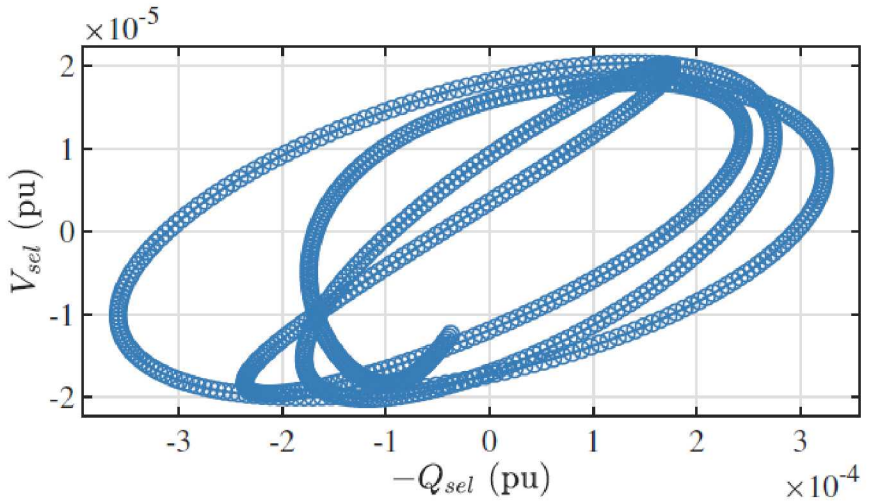


(b) Q-V unfiltered

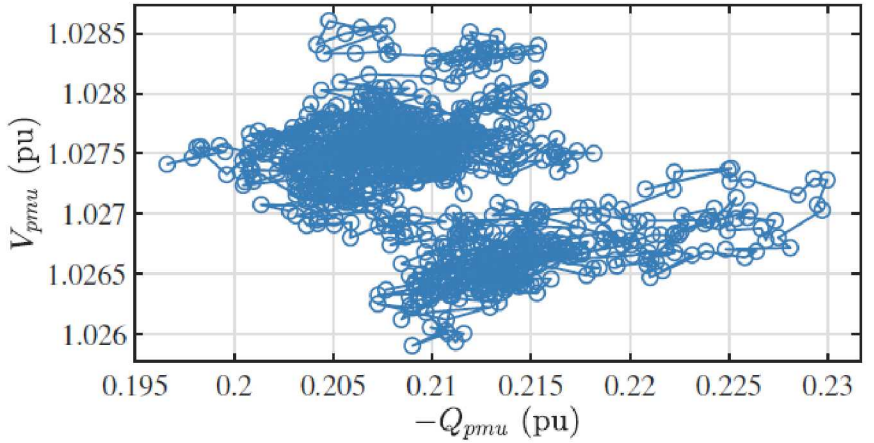
- Based on ambient operation
- In Datasets 8 and 10 the STATCOM was partially out of service

Generator Performance Evaluation Results – Ambient Data

Dataset	Droop (%)	T (ms)
1	6.514	561.73
2	12.161	509.35
3	20.055	1477.96
4	15.076	1033.97
5	18.029	989.40



(a) Q-V



(b) Q-V unfiltered

- Based on ambient operation
- Changes in voltage very small

Conclusions

- Voltage control performance can be monitored using voltage and reactive power signals measured at the equipment output
- Proposed Algorithm can work on
  - Disturbance data
  - Ambient operation data
- Performance estimates for
  - STATCOM
  - Excitation systems for synchronous generators
- Future Work
  - Use algorithm to estimate control performance of wind turbine generators
  - Implement real time control performance evaluation

Acknowledgements

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