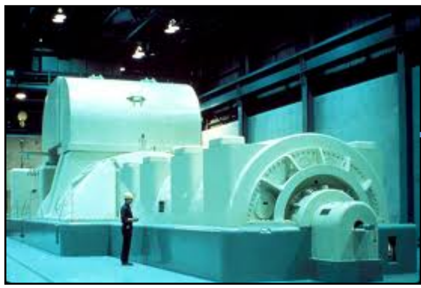
Frequency Stability Analysis for Inverters in Low Voltage Distribution Systems

Chung-Ching Chang
EE292K Final Presentation
June 12, 2012

* Under the instruction of Prof. Dimitry Gorinevsky and Prof. Sanjay Lall
** Based on the previous work by Eric Glover

Traditional Power Grid



Generation

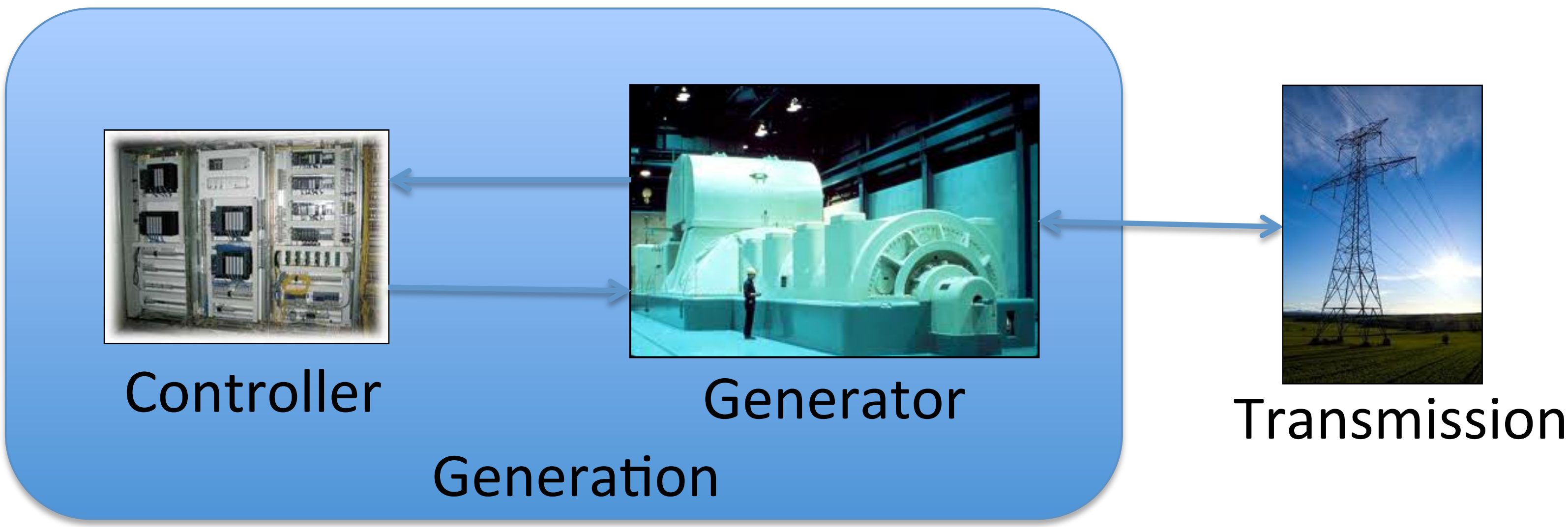
Transmission

Distribution

Load

- Unidirectional
- Transform LV/HV for transmission

Frequency Control in Generation



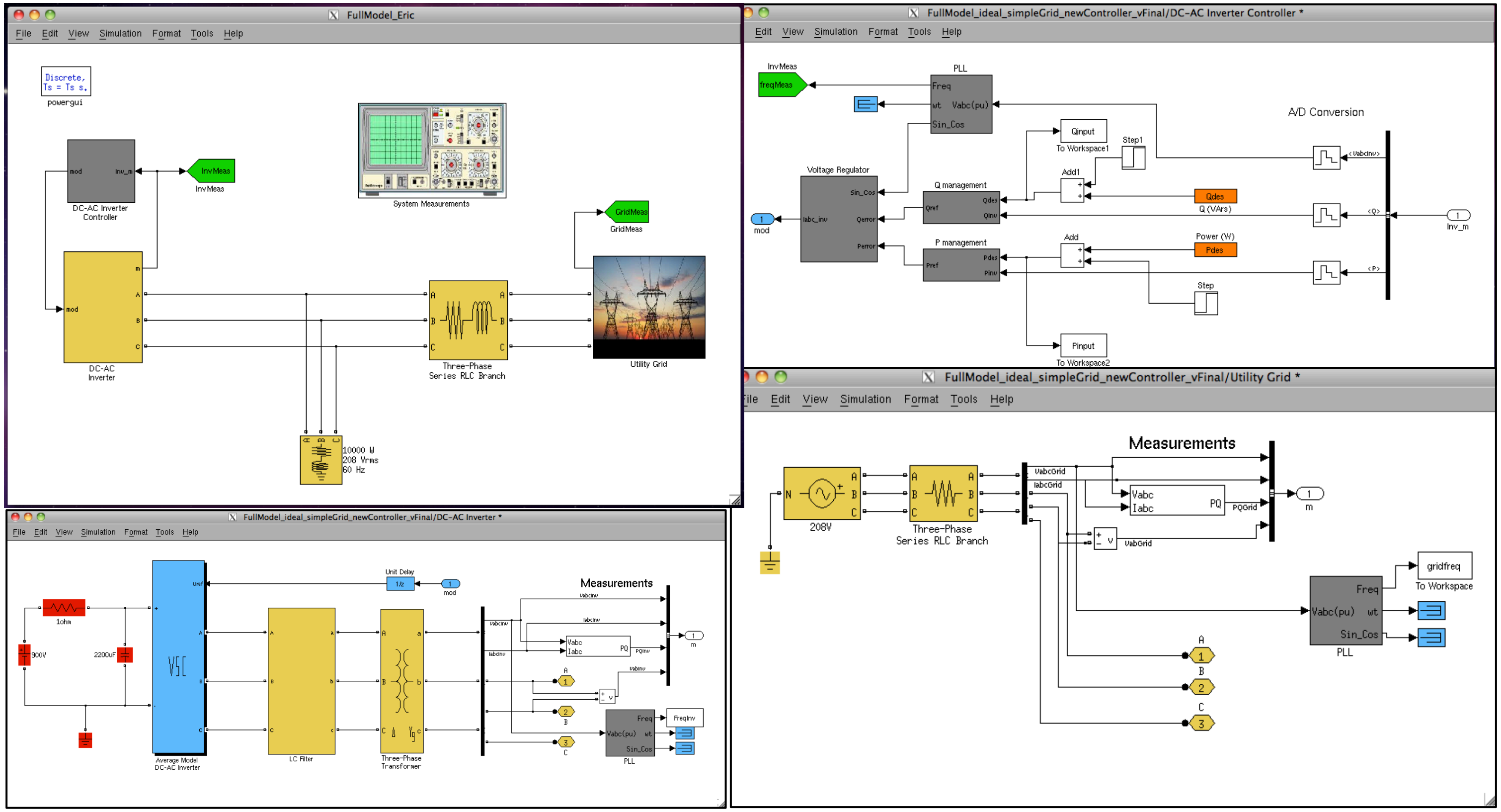
- Primary control
  - Regulates frequency vs. output power
- Secondary control
  - Restores frequency by adjusting turbine valves

Distributed Generation

- Gridtie Inverters
- Droop Inverters

Detailed Simulation

- SimPowerSystems: 3-phase Utility Grid, Inverter, Controls



Detailed Stability Analysis

- Run detailed simulation to ensure the system is stable
  - With all reasonable combinations of 20 parameters
  - 5 samples for each parameter
  - Each simulation takes 3 minutes
- Total simulation time is 0.5 Billion Years
  - $5^{20} \cdot 180s = 1.72 \cdot 10^{16}s$ = 544 Million Years

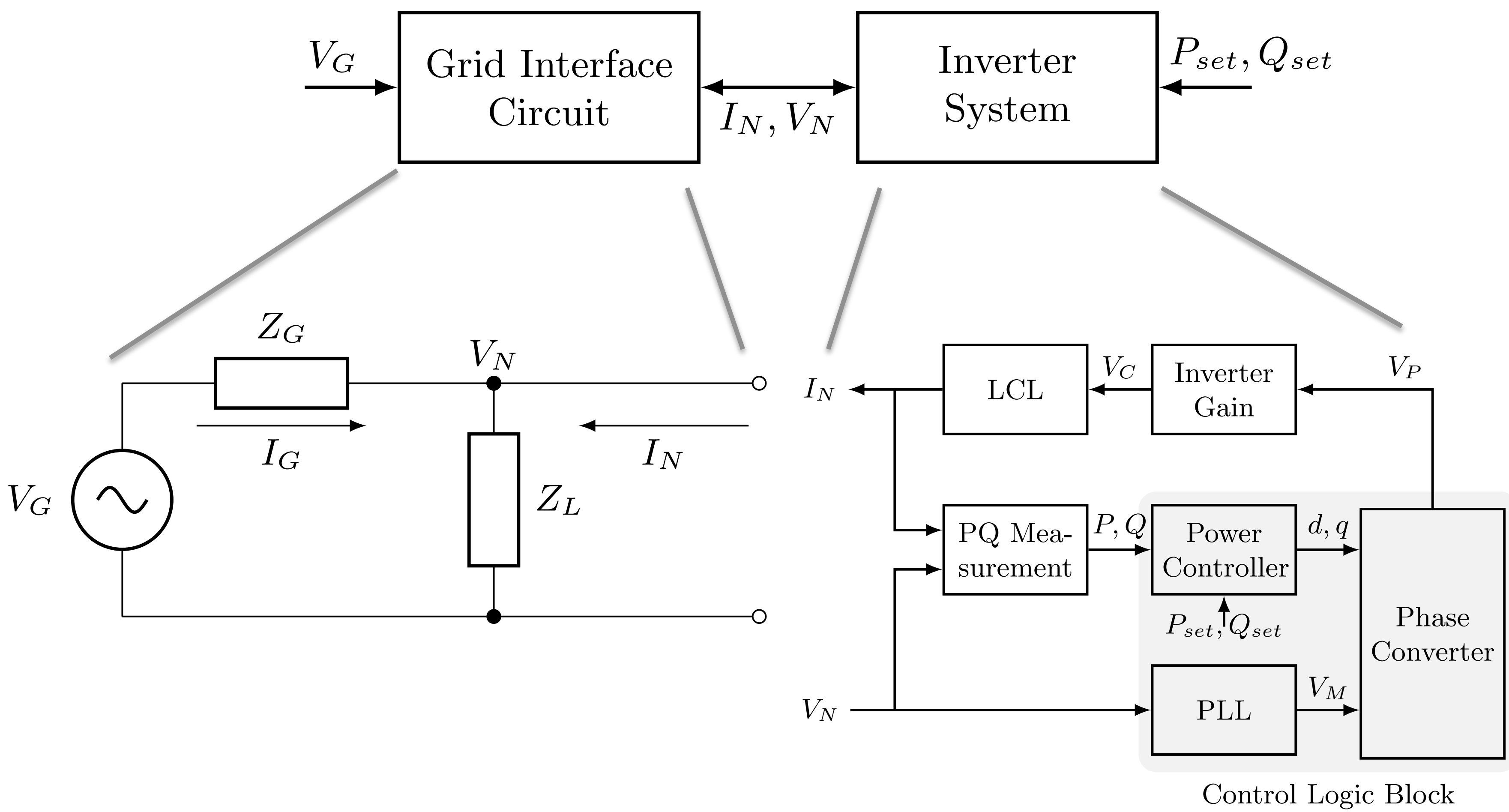
Surrogate Model

- Single phase system
- System linearized around the steady-state
- Lower computational complexity

	Detailed model	Surrogate model
Number of samples	5^{20}	5^{8}
Simulation time	~ 3 minutes	~ 1 second
Total time	$1.72 \cdot 10^{16}$ second	$3.9 \cdot 10^{5}$ second
Speed-up		~ x 10^{11}

* More speed-up with sparser parameter samples

Surrogate Model

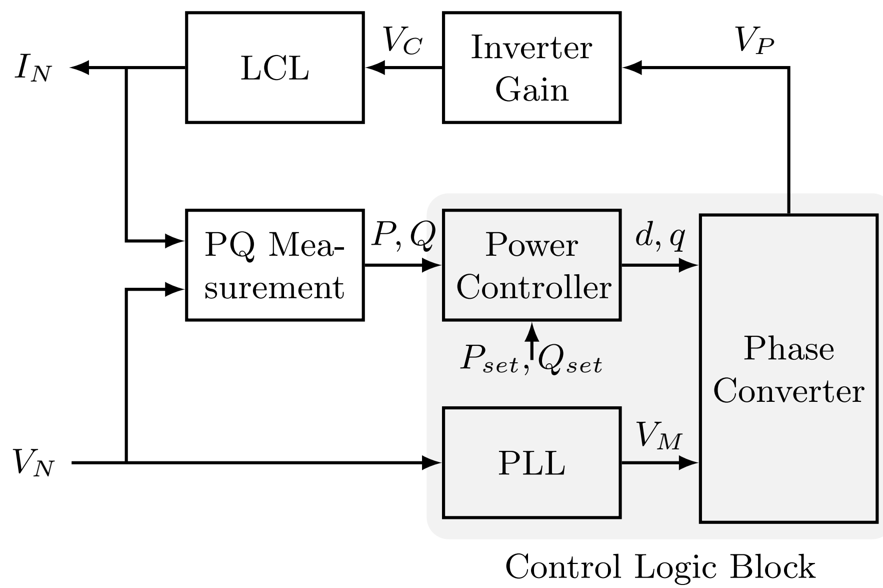


Gridtie Inverters

- Inject power into the grid with unity power factor:

  $P = P_{set},$

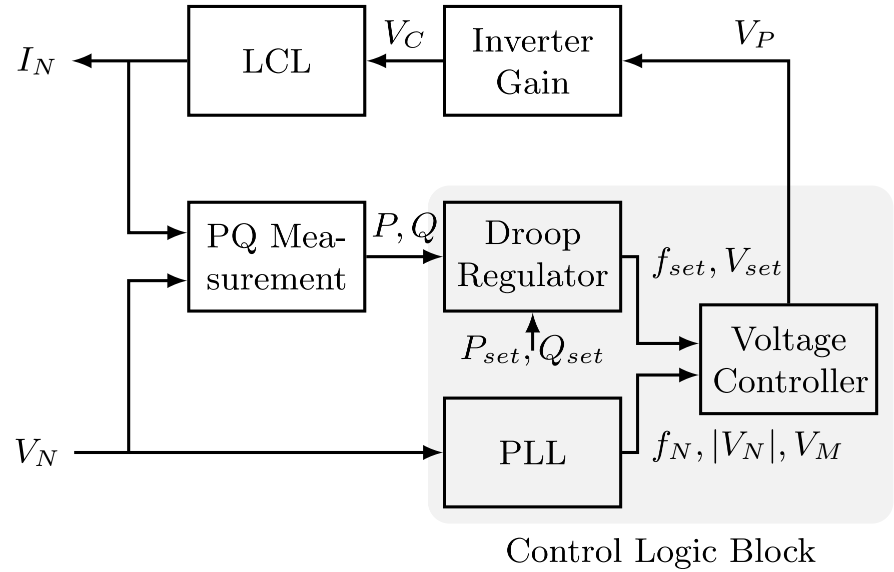
  $Q = Q_{set} = 0$



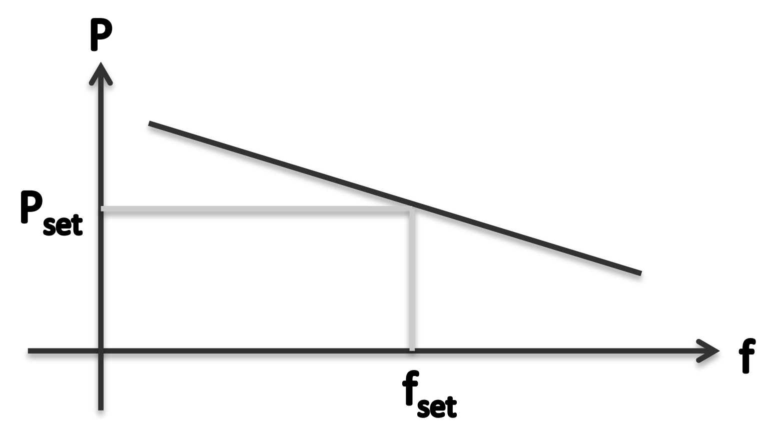
Droop Inverters

- Droop equations:

$$f_{set} = f_0 - K_p (P - P_{set}),$$
$$V_{set} = V_0 - K_v(Q - Q_{set})$$

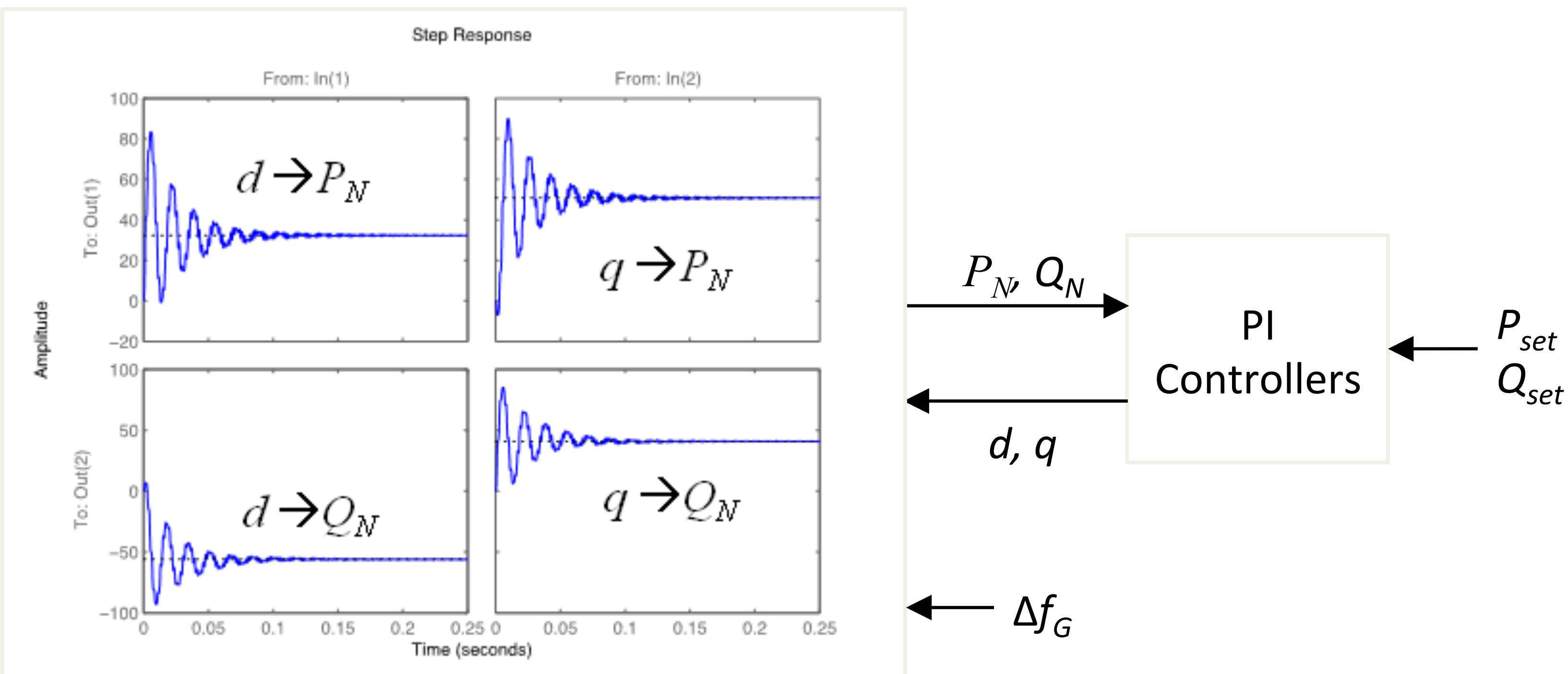


- This adds the inertia to the inverters as that of the primary control in generators



Control Framework

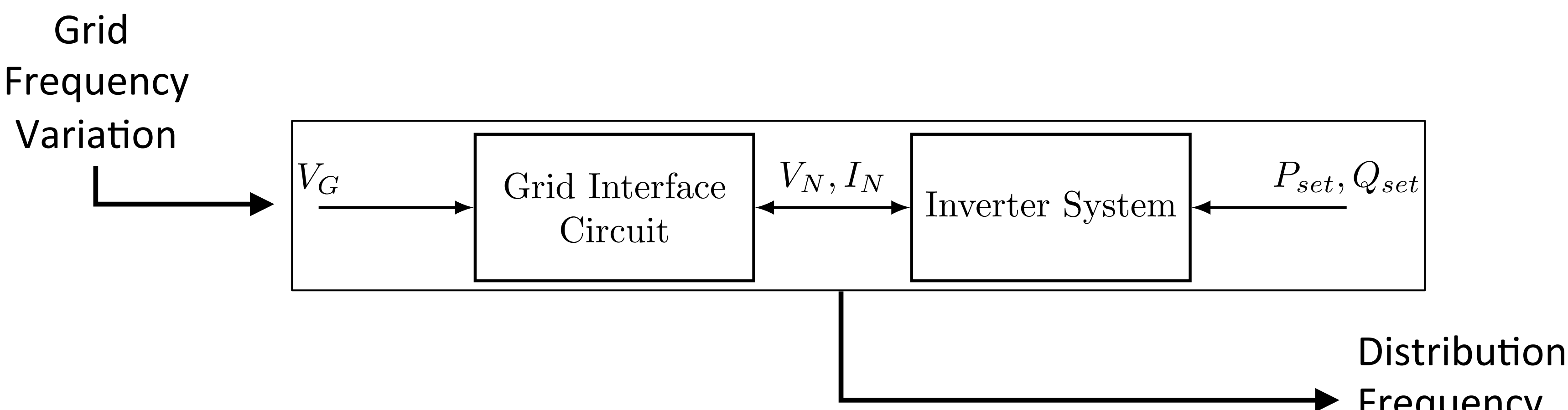
- Stability issues in transient:
  - Set points P_{set}, Q_{set}
  - Exogenous frequency disturbance Δf_G



Stability Analysis

- H_∞ norm measures the worst case disturbance amplification from the frequency of V_G to that of V_N

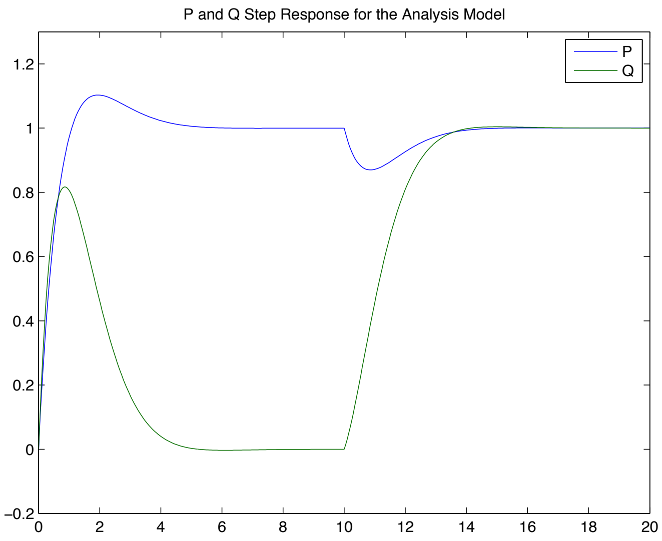
$$\|T\|_\infty = \sup \frac{\|\Delta\omega_{V_G}\|_\infty}{\|\Delta\omega_{V_N}\|_\infty}$$



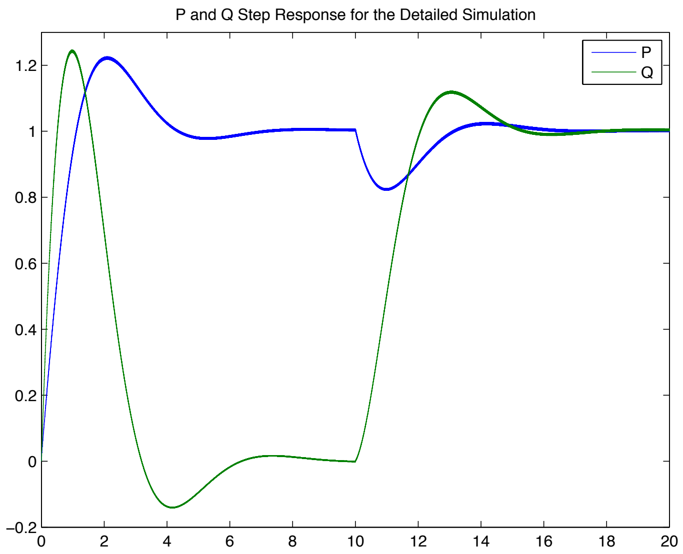
$$\Delta\omega_{V_N} = T(\Delta\omega_{V_G})$$

Surrogate Model Verification

- Surrogate model matches the detailed simulation model reasonably well



Surrogate model



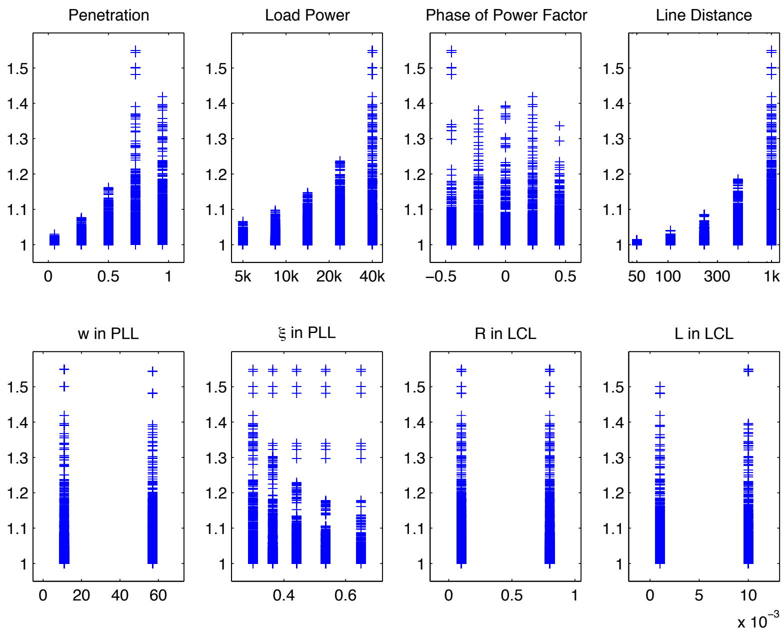
Simulation model

Analysis Results

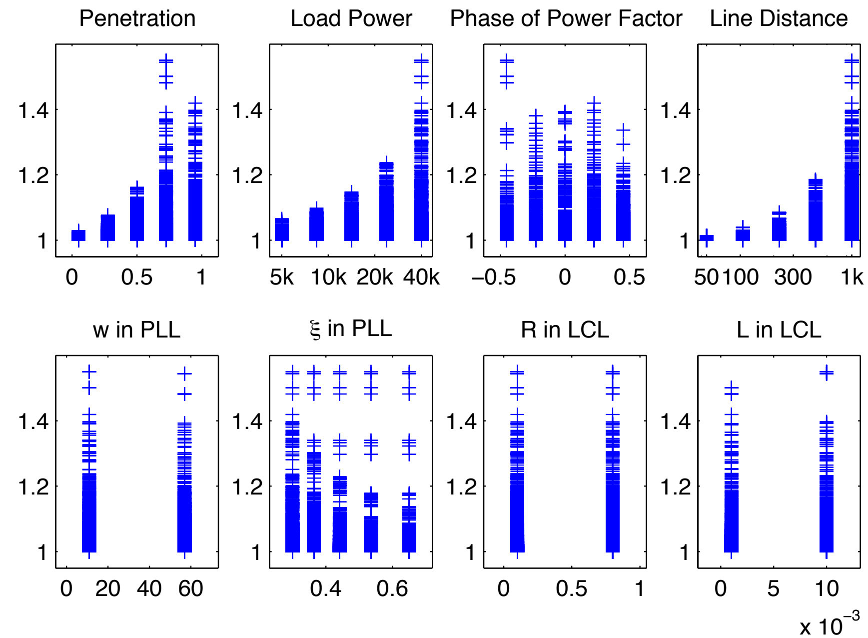
- Range of parameters

Parameters	Minimum Value	Maximum Value
Penetration a	0.05	0.95
Load power P_L	5kW	40kW
Power factor $\cos(\psi)$	0.9	1.00
Line length l	0.25km	1km
PLL rise time	0.02s	0.1s
PLL overshoot	23%	45%
LCL power loss	$1 \cdot 10^{-2}$Watt	5Watt
LCL settling time	0.12s	0.22s

Analysis Results



Gridtie Inverter



Droop Inverter

H∞ norm is always less than 2 in all samples explored!

Conclusion

- Frequency stability analysis is evaluated for both gridtie and droop inverters
- Grid frequency disturbance is amplified roughly in proportional to penetration, load power, and line distance
- For a well-tuned inverter, this amplification is reasonably small
- However, the power factor may drop below 0.85 as viewed from the upstream as penetration increases, violating IEEE 1547