Simulation Models for Single Phase Compressor Motors

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Simulation Models for Compressor Load Models

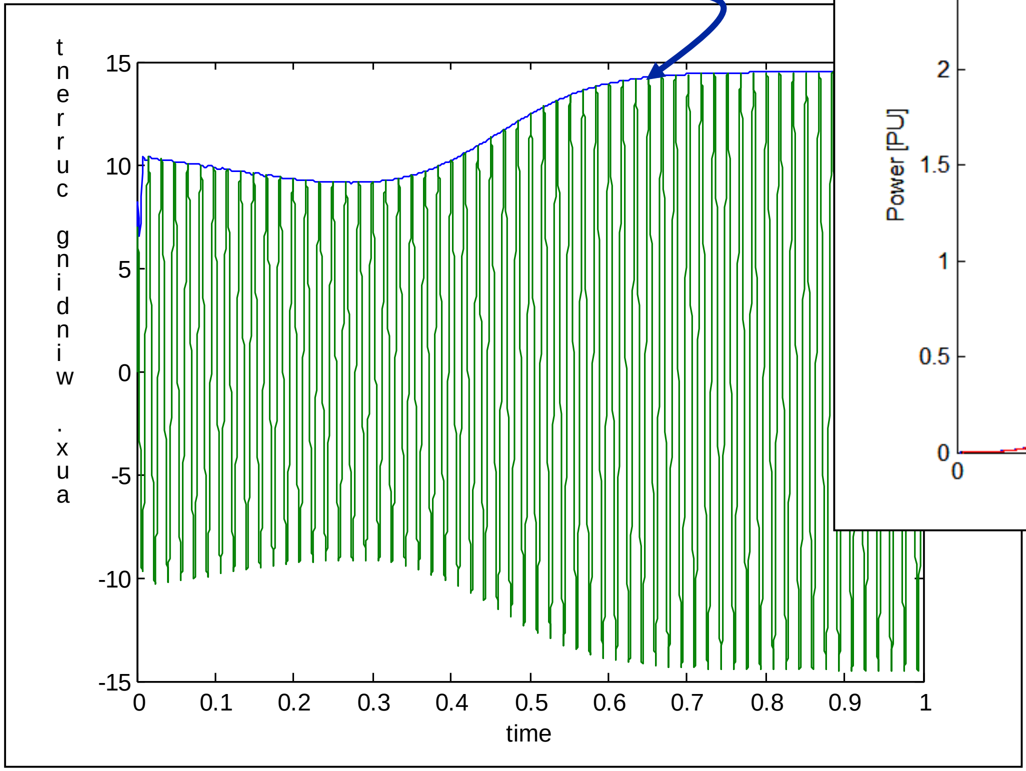
Option 1: Detailed motor models, and single-phase network models. Useful for research, hopefully not needed for grid-scale simulations.

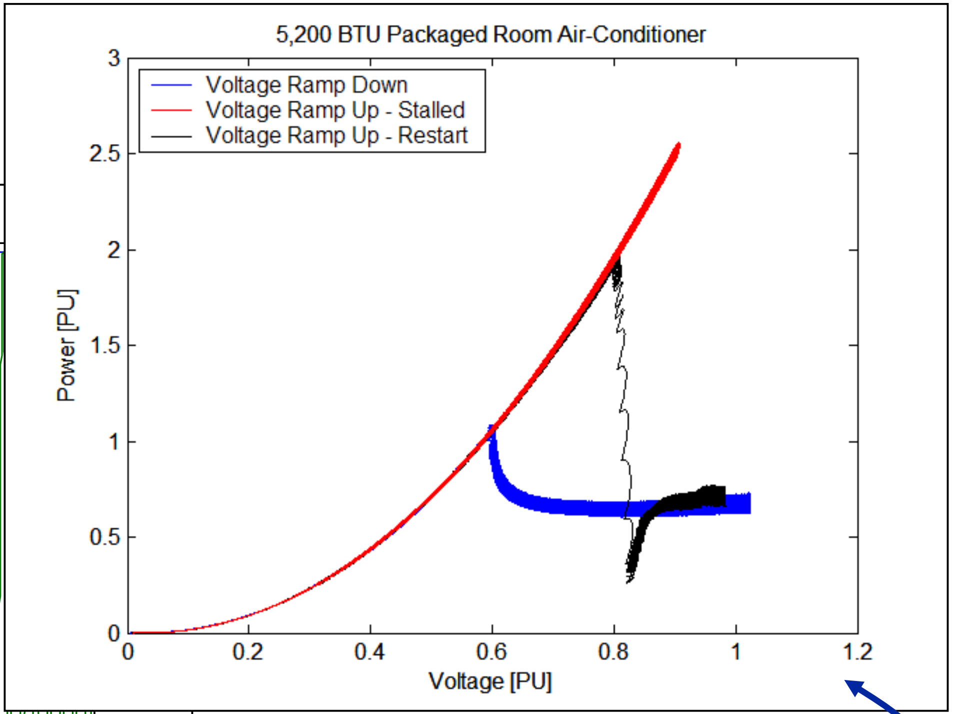
Option 2: Adapt models for grid simulations

- static performance model, current model simplistic, somewhat pessimistic.
- dynamic phasor model, complicated, doesn't capture subcycle influences (yet).

Single-Phase Motor Models for Grid

"Dynamic Phasor" Model





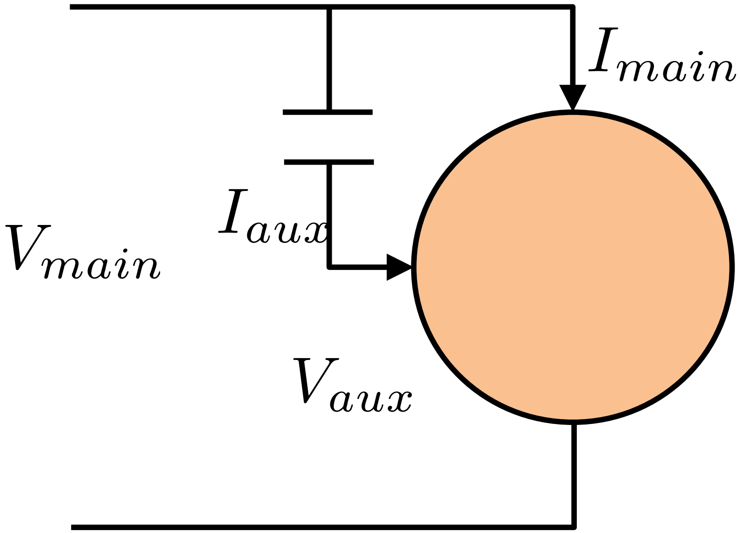
"Performance" Model

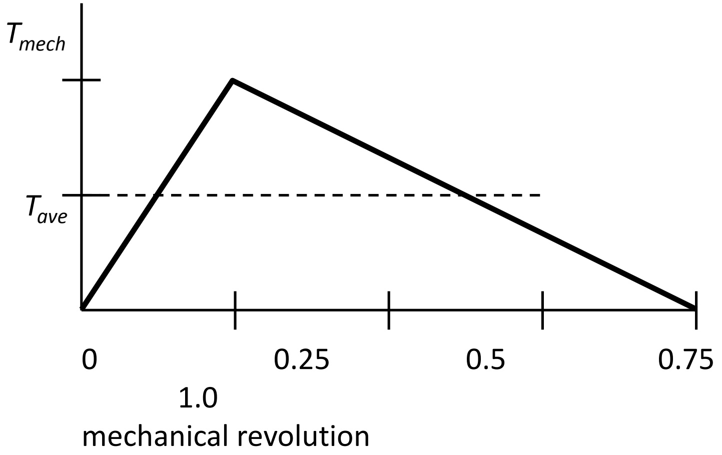
Important Questions about Grid Simulations

- To what extent do single-phase, point-on-wave effects matter? Examine with single-phase motor simulations and tests.
- To what extent can impacts be aggregated?

  Do all motors stall during a FIDVR event?

Single Phase Compressor Simulation Model

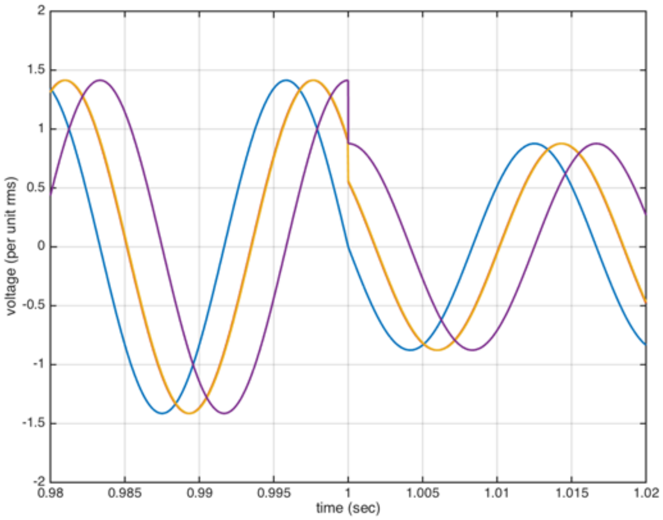




Reciprocating Compressor Mechanical Load

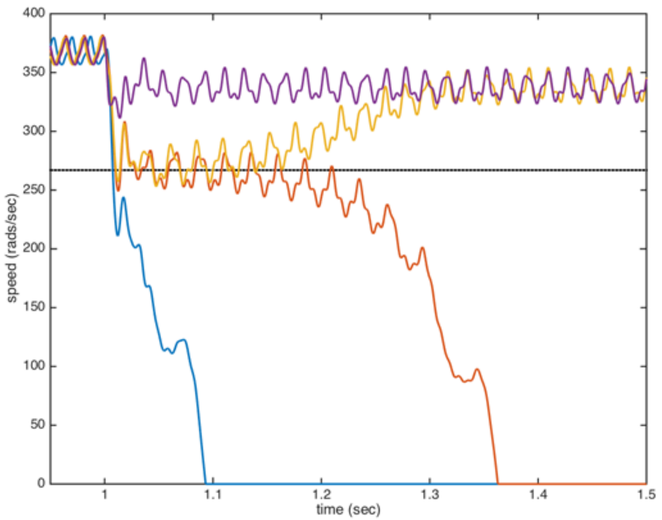
Point-on-Wave Effects

Simulations of Single-Phase Compressor Motor



Applied voltage. The disturbance occurs at different points along the sinusoid: peak, zero crossing, in between.

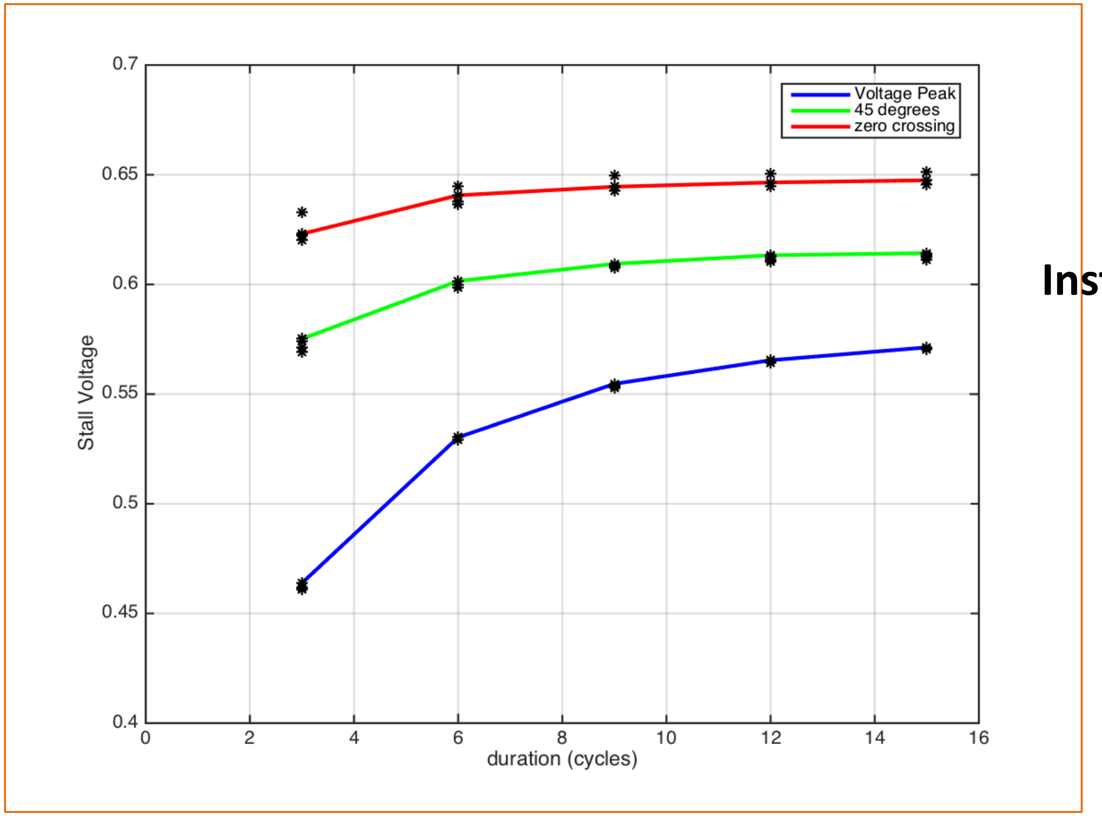
Instantaneous drop to 62% nominal for 3 cycles.



Speed for the different applied voltages. Worst case: zero crossing disturbance.

Point-on-Wave Effects

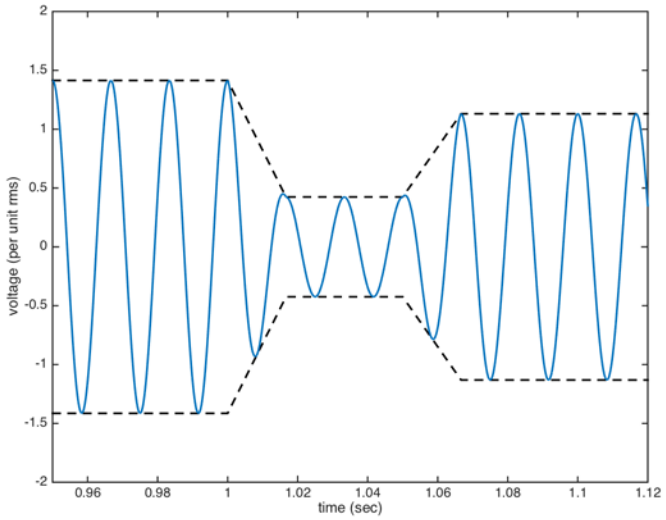
Stall Voltage vs fault duration, and point-on-wave variation.



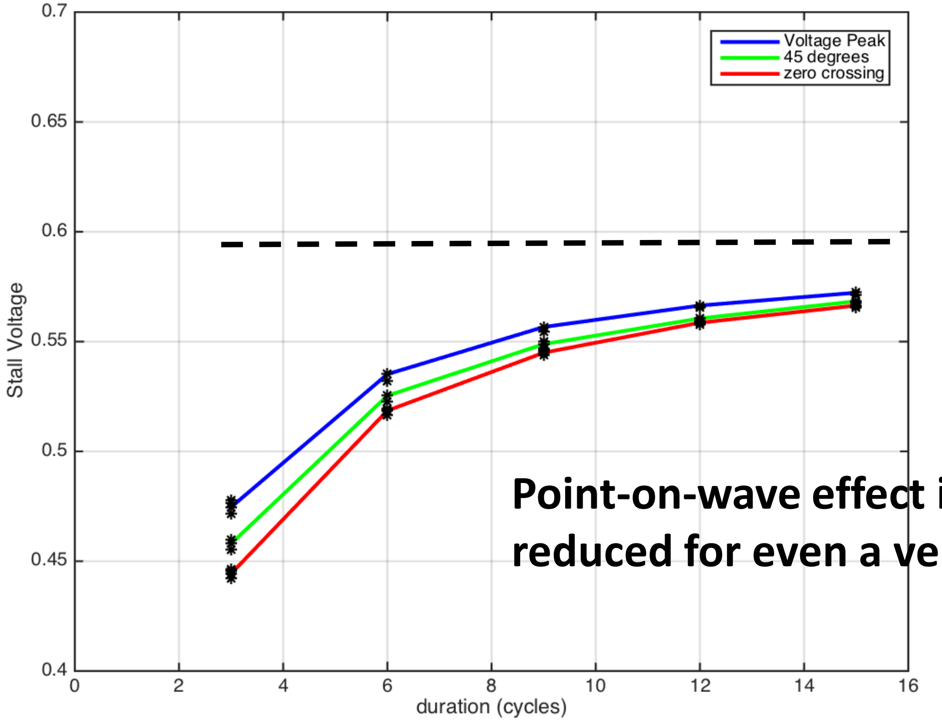
Instantaneous voltage drop

Point-on-Wave Effects

- Ramp Voltage Instead:



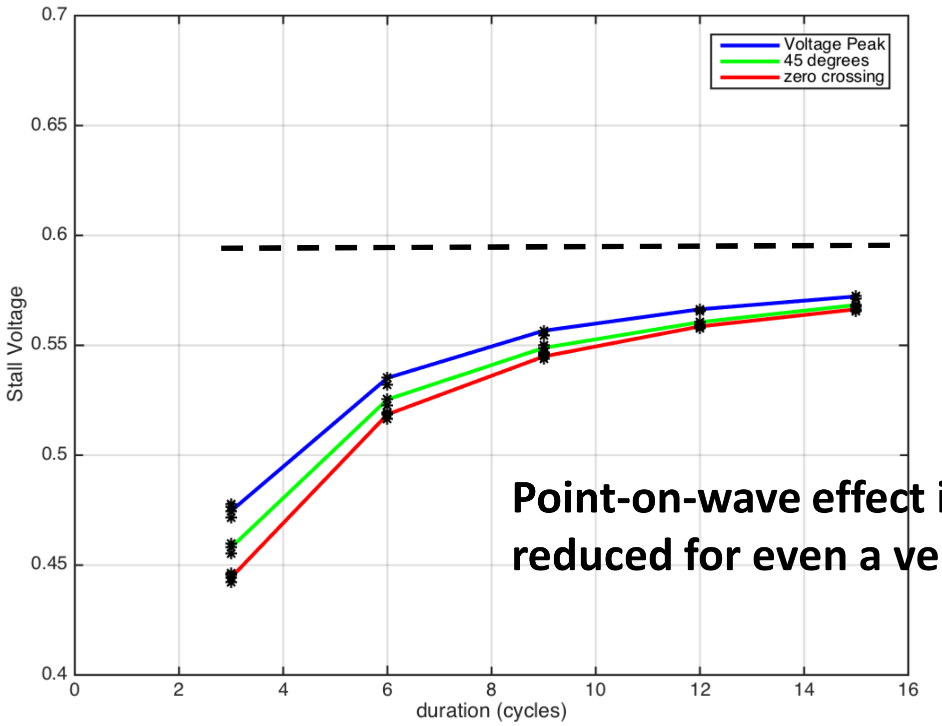
Performance Model Characteristic for reference



Point-on-wave effect is greatly reduced for even a very short ramp.

Point-on-Wave Effects

- These results suggest a reason why FIDVR events don't cascade beyond an event feeder.
- Locally, A/C motors stall in response to event.



Further away, the filtered voltage may exceed threshold.

Performance Model Characteristic for reference

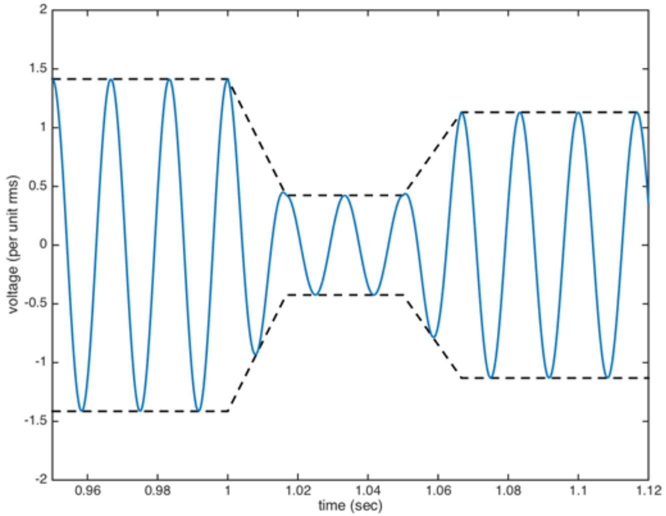
Point-on-wave effect is greatly reduced for even a very short ramp.

Laboratory Tests

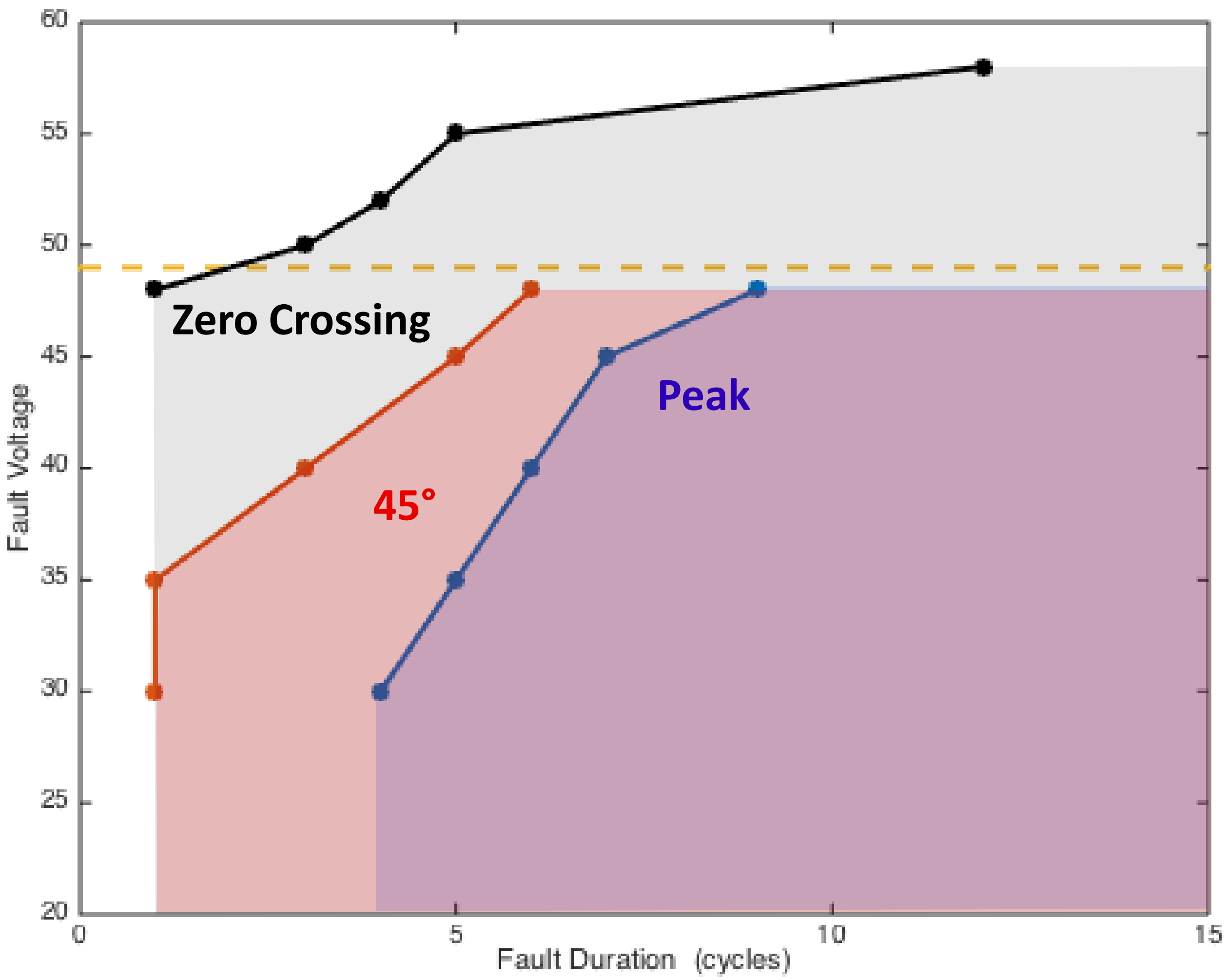
- Air Conditioner Tests at BPA Facility
- Test Point-on-Wave Response, with and without ramp.
- Scroll Compressor

Voltage dip to 48, 45, 40, 35 and 30% nominal
Recovery voltage at 90% nominal.

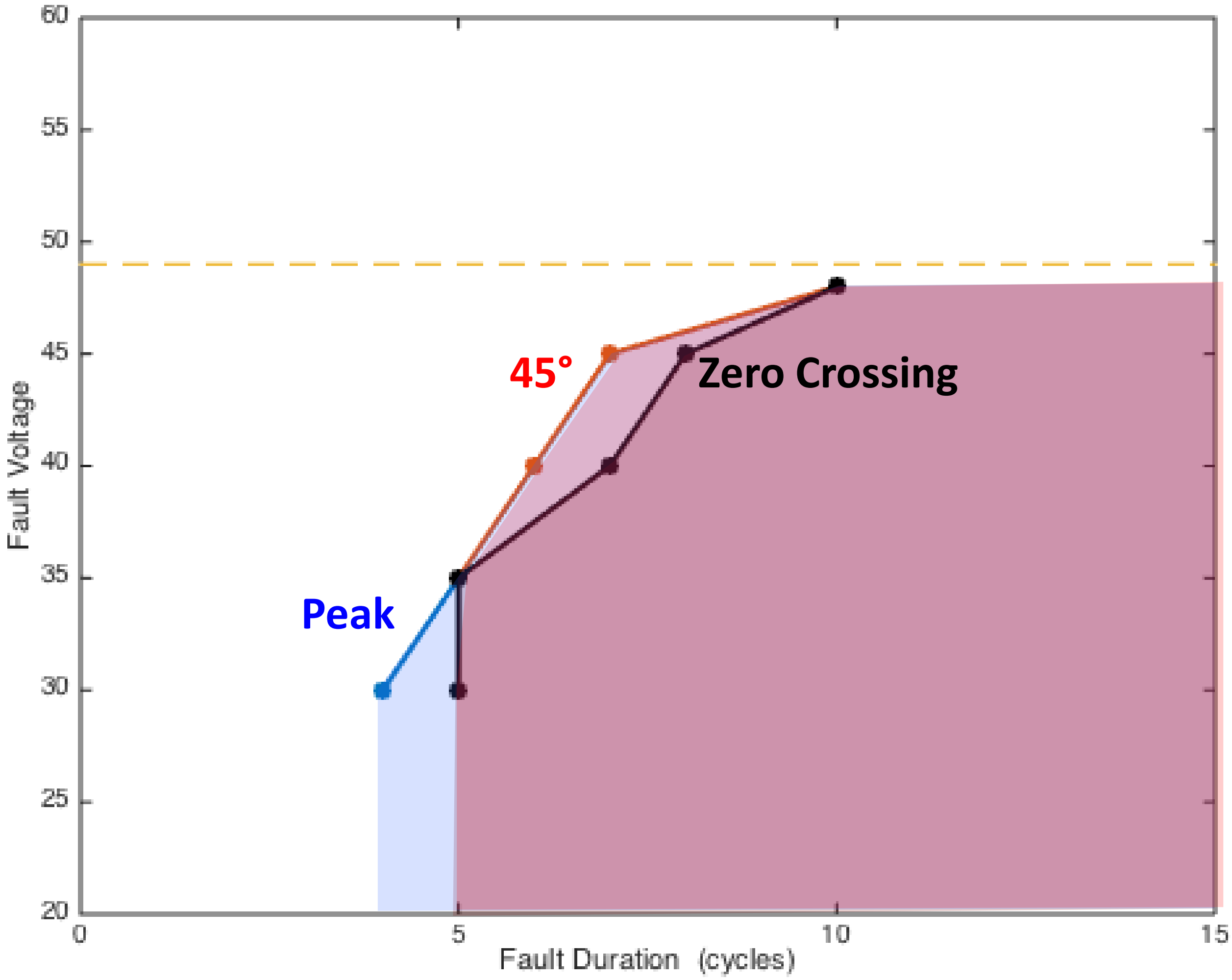
Find fault duration to result in a change in operating characteristic (not stall)



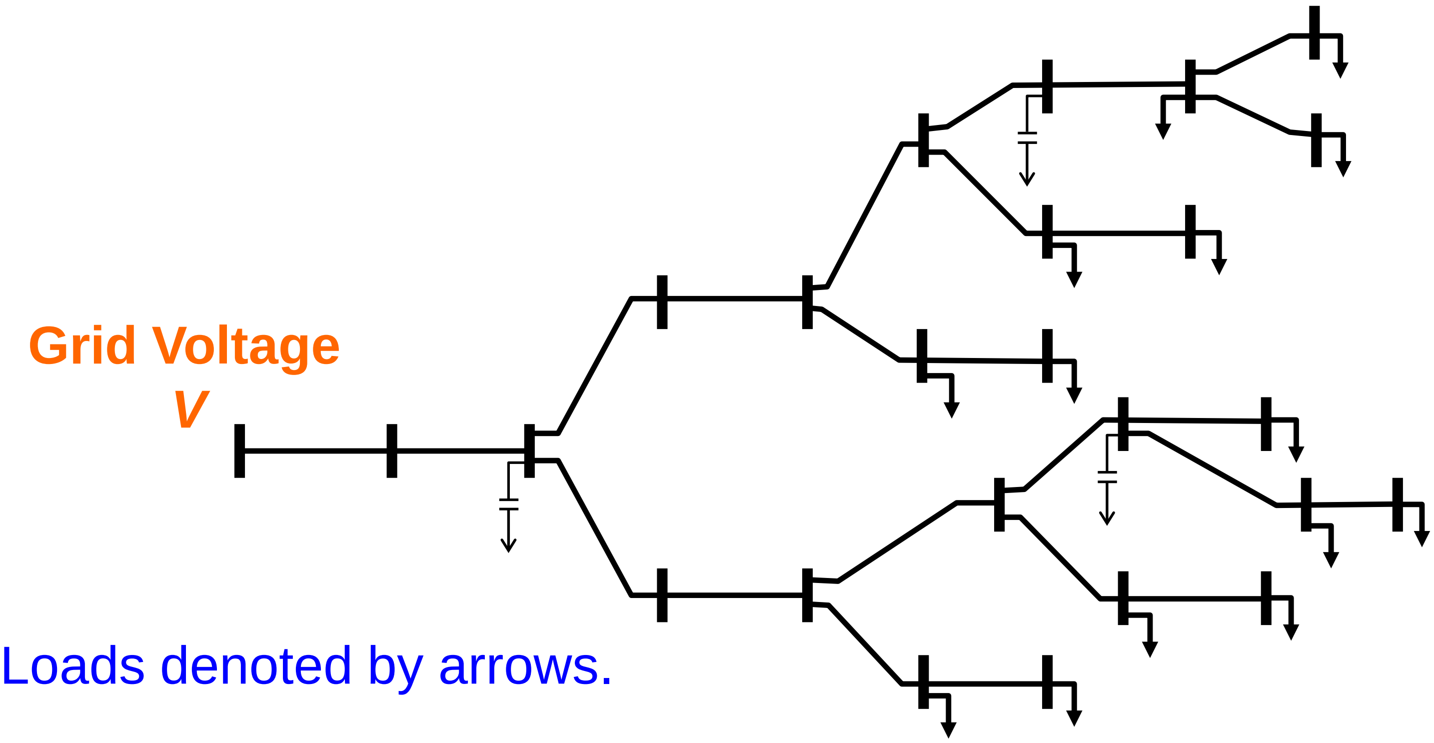
Fault Regions, Instantaneous Voltage Dip



Fault Region: 1 Cycle Ramp in Voltage Dip



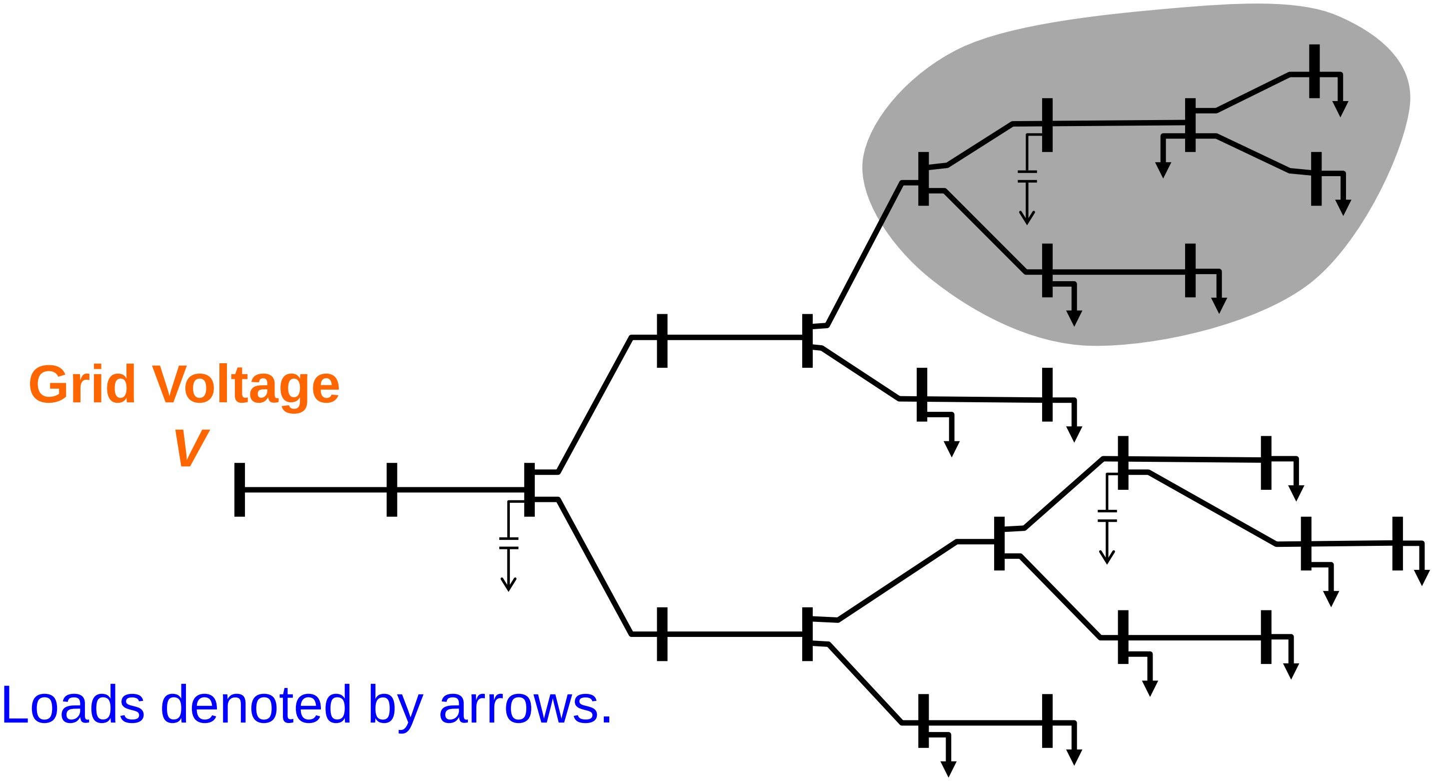
Do All Motors Stall?



25 Buses, 13 loads, tree distribution network, single connection to the grid.

Is it possible for a fraction of motors to stall in this network without stalling them all?

Do All Motors Stall?



100% Compressor Load: They all stall.

50% Compressor, 50% Impedance, some may stall.

(up to 5 maximum in this example)

Conclusions

A dynamic phasor models may be suitable for grid-scale simulations because

- point-on-wave effects may be naturally mitigated by smoothing in disturbance away from the event location.
- allow aggregation of stall effects.

Dynamic Phasor Model

$$\left|V_s\right| = \left(r_{ds} + j\frac{\omega_s}{\omega_b}X'_{ds}\right)\left(I_{ds}^R + jI_{ds}^I\right) + j\left(\frac{\omega_s}{\omega_b}\right)\frac{X_m}{X_r}\left(\Psi_{dr}^R + j\Psi_{dr}^I\right)$$

$$\left|V_s\right| = \left(r_{qs} + j\frac{\omega_s}{\omega_b}X'_{qs} + j\frac{\omega_b}{\omega_s}X_c\right)\left(I_{qs}^R + jI_{qs}^I\right) + j\left(\frac{\omega_s}{\omega_b}\right)\frac{nX_m}{X_r}\left(\Psi_{qr}^R + j\Psi_r^I\right)$$

$$\begin{bmatrix}\left(\Psi_f^R + j\Psi_f^I\right)\\ \left(\Psi_b^R + j\Psi_b^I\right)\end{bmatrix} = \left(\frac{1}{2}\right)\begin{bmatrix}1 & -j\\ 1 & j\end{bmatrix}\begin{bmatrix}\left(\Psi_{dr}^R + j\Psi_{dr}^I\right)\\ \left(\Psi_{qr}^R + j\Psi_{qr}^I\right)\end{bmatrix} \qquad \begin{bmatrix}\left(\Psi_{dr}^R + j\Psi_{dr}^I\right)\\ \left(\Psi_{qr}^R + j\Psi_{qr}^I\right)\end{bmatrix} = \begin{bmatrix}1 & 1\\ j & -j\end{bmatrix}\begin{bmatrix}\left(\Psi_f^R + j\Psi_f^I\right)\\ \left(\Psi_b^R + j\Psi_b^I\right)\end{bmatrix}$$

$$\begin{bmatrix}\left(I_f^R + jI_f^I\right)\\ \left(I_b^R + jI_b^I\right)\end{bmatrix} = \left(\frac{1}{2}\right)\begin{bmatrix}1 & -jn\\ 1 & jn\end{bmatrix}\begin{bmatrix}\left(I_{ds}^R + jI_{ds}^I\right)\\ \left(I_{qs}^R + jI_{qs}^I\right)\end{bmatrix} \qquad \begin{bmatrix}\left(I_{ds}^R + jI_{ds}^I\right)\\ \left(I_{qs}^R + jI_{qs}^I\right)\end{bmatrix} = \begin{bmatrix}1 & 1\\ j/n & -j/n\end{bmatrix}\begin{bmatrix}\left(I_f^R + jI_f^I\right)\\ \left(I_b^R + jI_b^I\right)\end{bmatrix}$$

$$T'_o\frac{d}{dt}\left(\Psi_f^R + j\Psi_f^I\right) = X_m\left(I_f^R + jI_f^I\right) - \left(sat(\Psi_f, \Psi_b) + j\left(\omega_s - \omega_r\right)T'_o\right)\left(\Psi_f^R + j\Psi_f^I\right)$$

$$\left(\Psi_b^R + j\Psi_b^I\right) = \frac{X_m\left(I_b^R + jI_b^I\right)}{\left(sat(\Psi_f, \Psi_b) + j\left(\omega_s + \omega_r\right)T'_o\right)}$$

$$\frac{2H}{\omega_b}\frac{d\omega_r}{dt} = \frac{X_m}{X_r}2\left(I_f^I\Psi_f^R - I_f^R\Psi_f^I - I_b^I\Psi_b^R + I_b^R\Psi_b^I\right) - T_{mech}$$

$$I_s = \left[\left(I_{ds}^R + jI_{ds}^I\right) + \left(I_{qs}^R + jI_{qs}^I\right)\right]e^{j\phi}$$