Analog and Digital Simulation of Microgrid Dynamics

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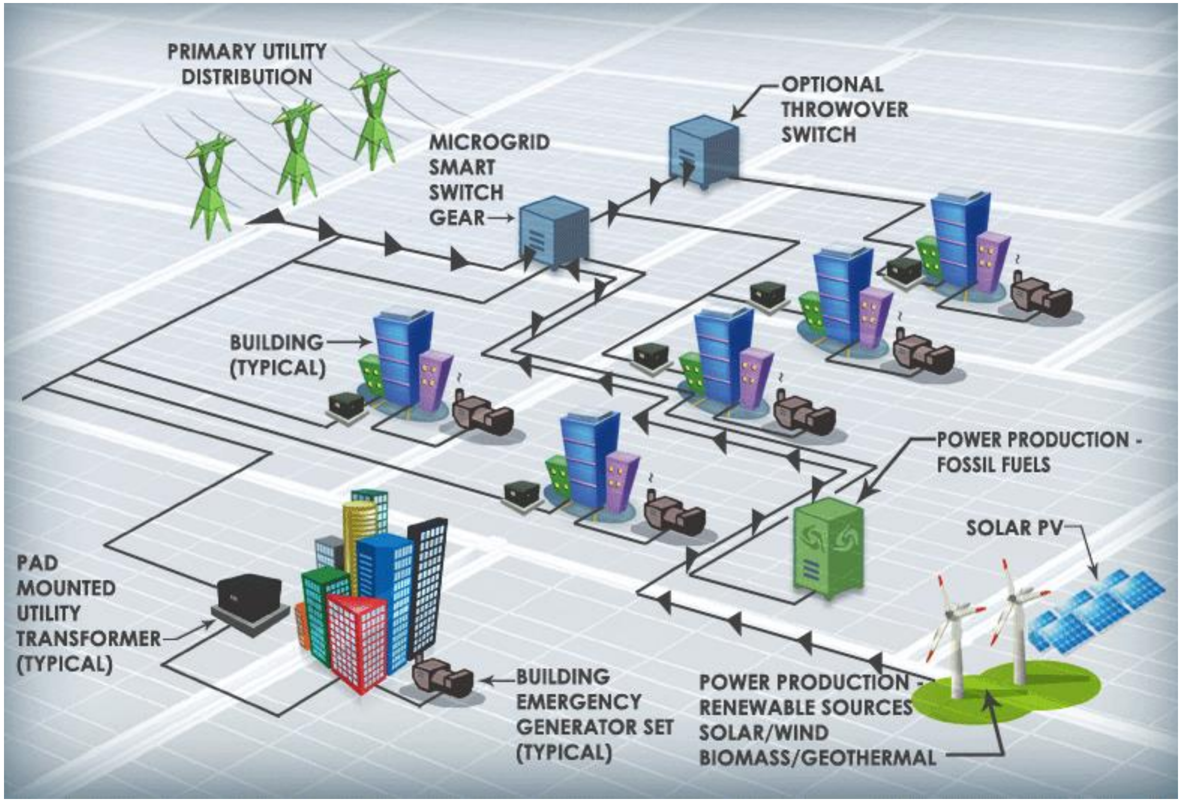
A Microgrid is either:

- A fragment of a power system
- A small power system

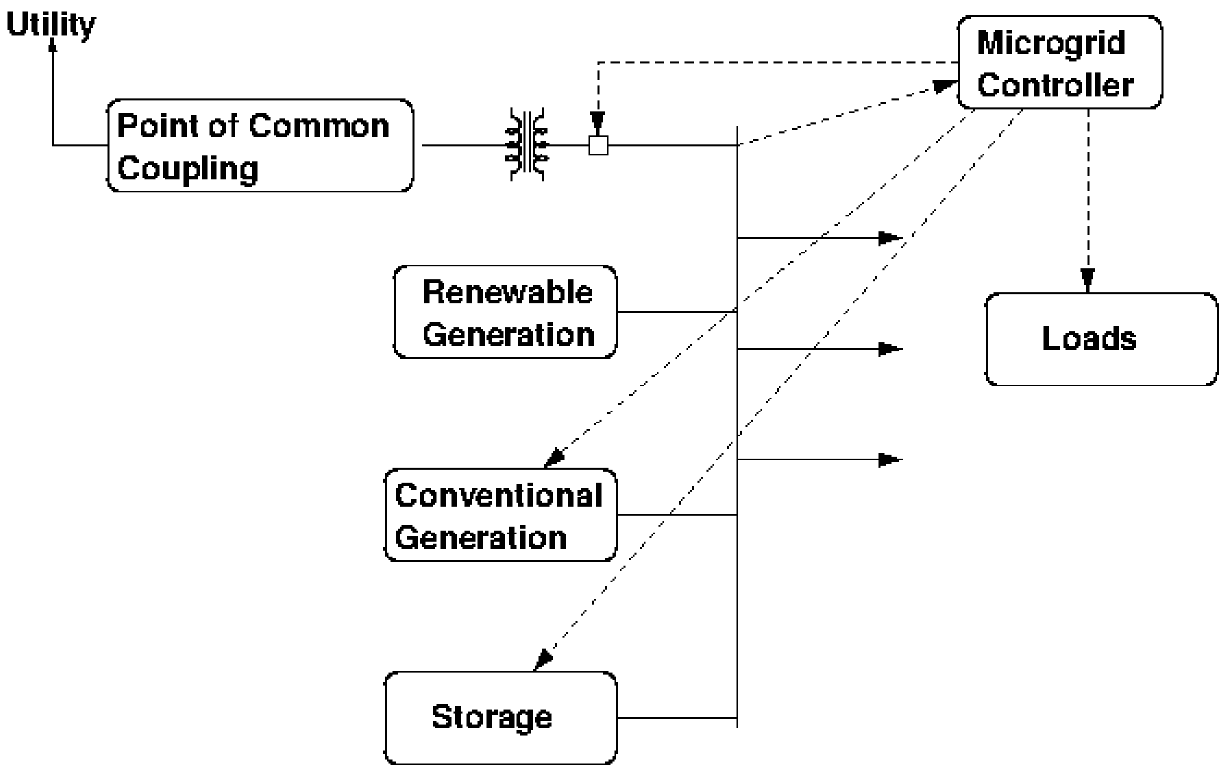
That can:

- Operate as a standalone system, or
- Operate in parallel with a large utility system



What is the role of a 'Microgrid'?

- Enhance Reliability?
- Facilitate incorporation of renewable generation?



Important issues related to microgrids:

Local Generation:

- Renewables: Solar and Wind
  Difficult to Control and Dispatch
- Cogeneration: Combined Heat and Power
  Dispatch and Control have other worries
- Conventional generation gives a little bit of a break
- Some generation is provided through inverters
  Even if controllable, has no inertia
  And may current limit

Loads

- Some loads may be responsive to system needs
- Some loads are constant power
- Some loads are constant impedance
- Induction Motor loads may be large and have special dynamics

Enhanced Reliability:

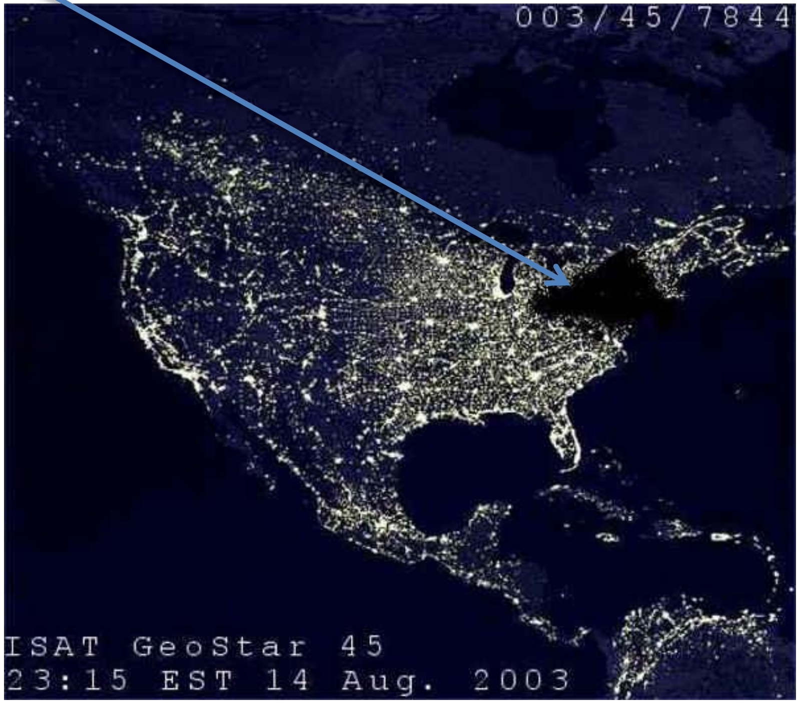
- Something goes wrong
- Not always as bad as this
- Examples:

  Aggressive trees
  Vehicle accidents
  Weather

May require islanding

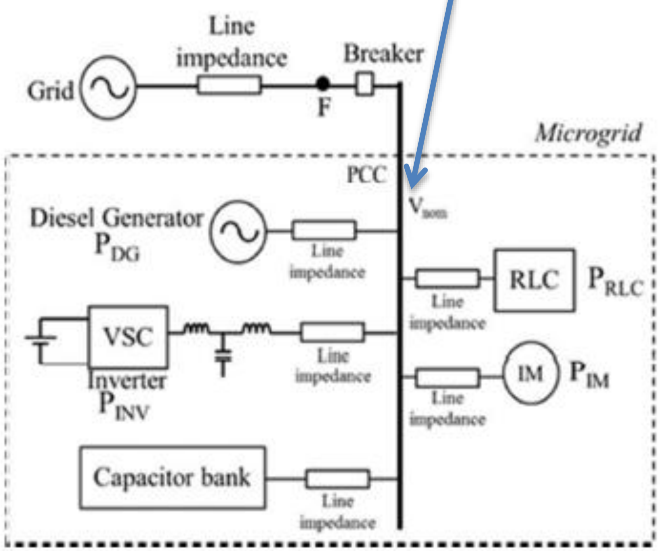
Control must:

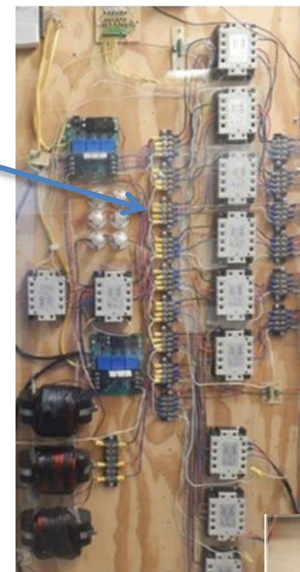
- Detect the problem
- Determine if ‘ride through’ is possible, and if not:
- Shut down connection at PCC
- Balance load with local generation
- Existence of local storage can help with this

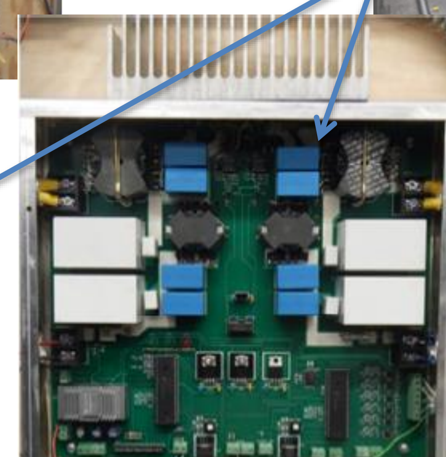


Studies of Microgrids at MIT: an Emulator with Physical Machines and Electronics

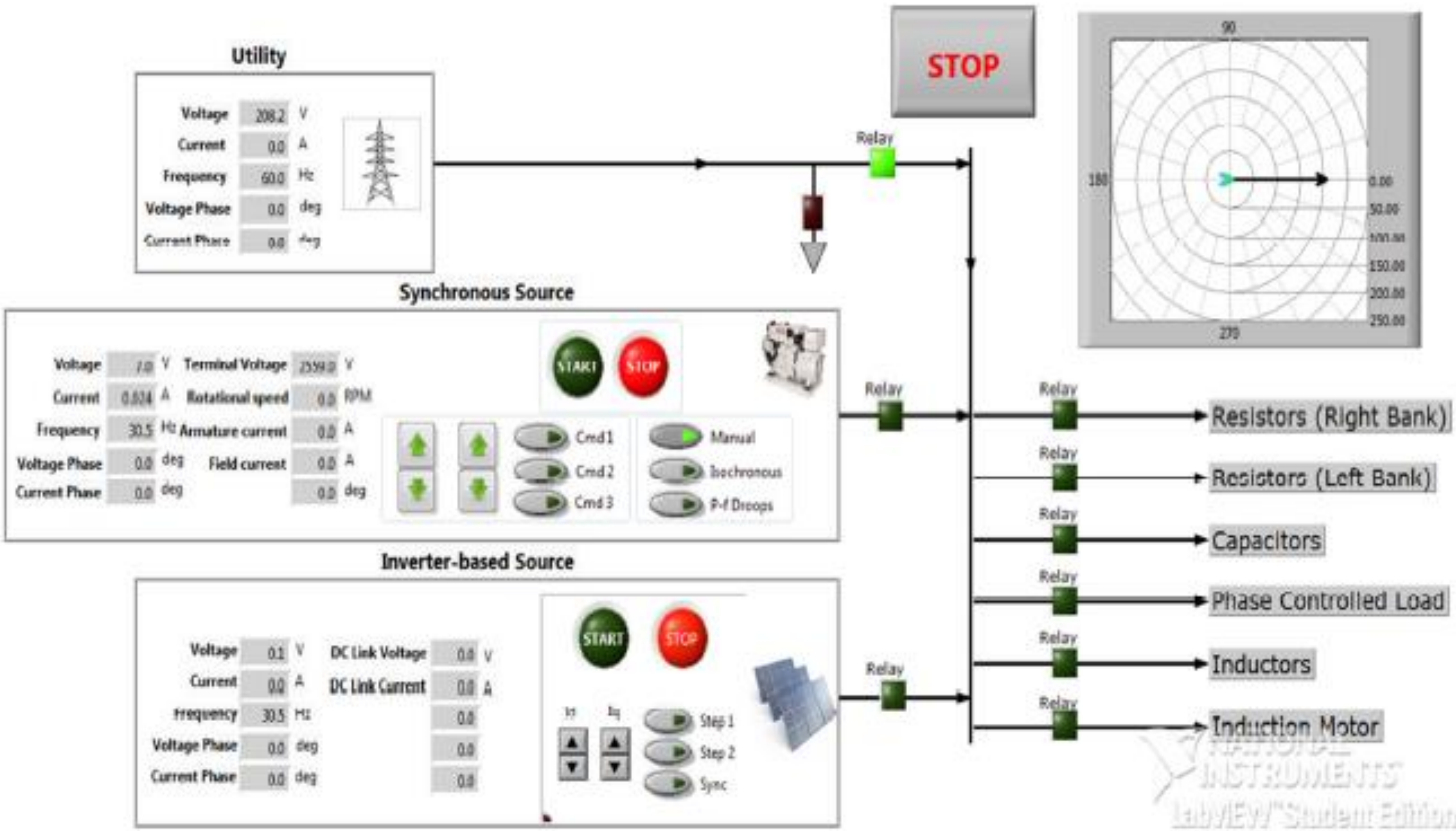
Main Bus





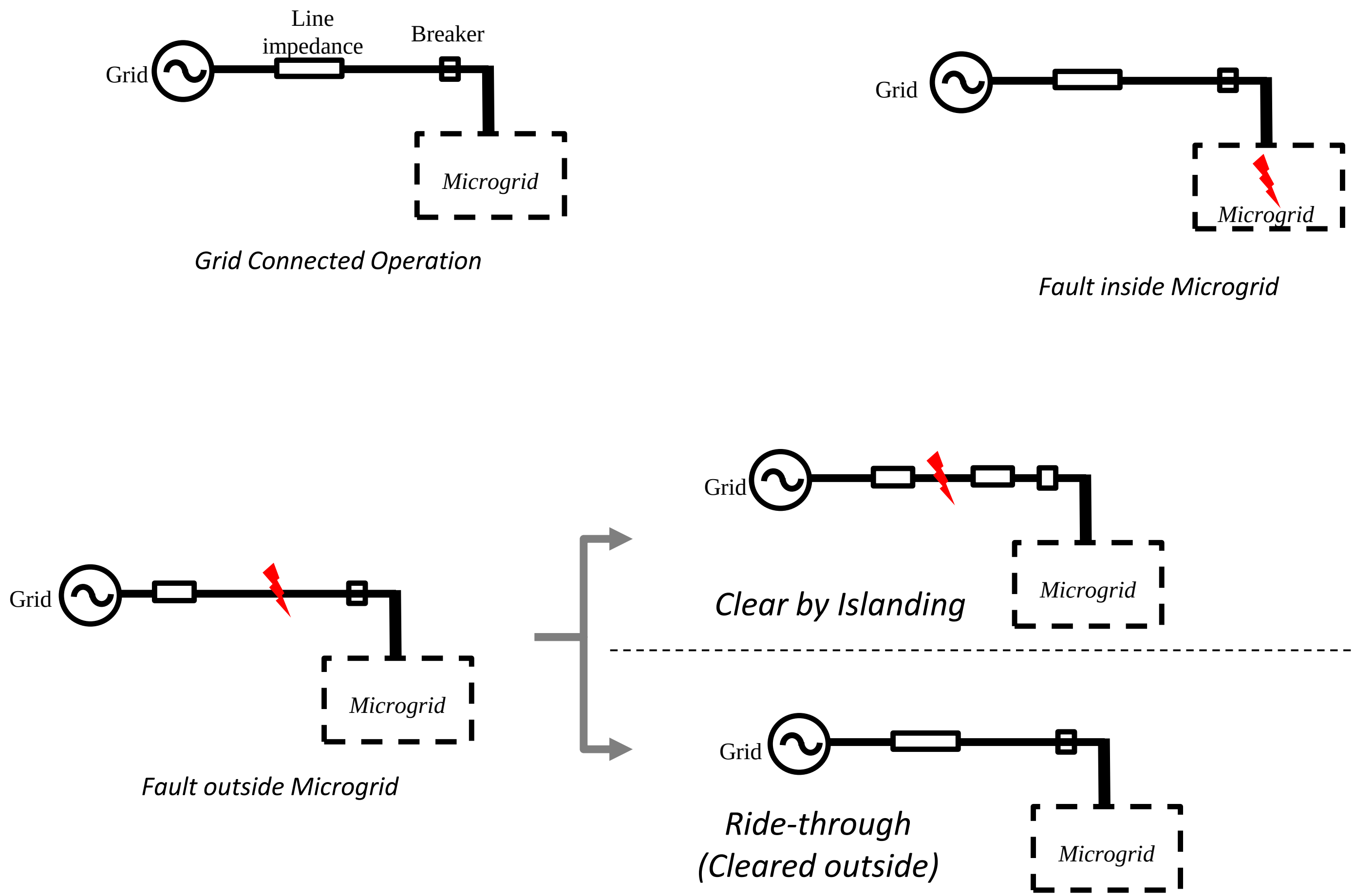


Diesel Generator Emulator

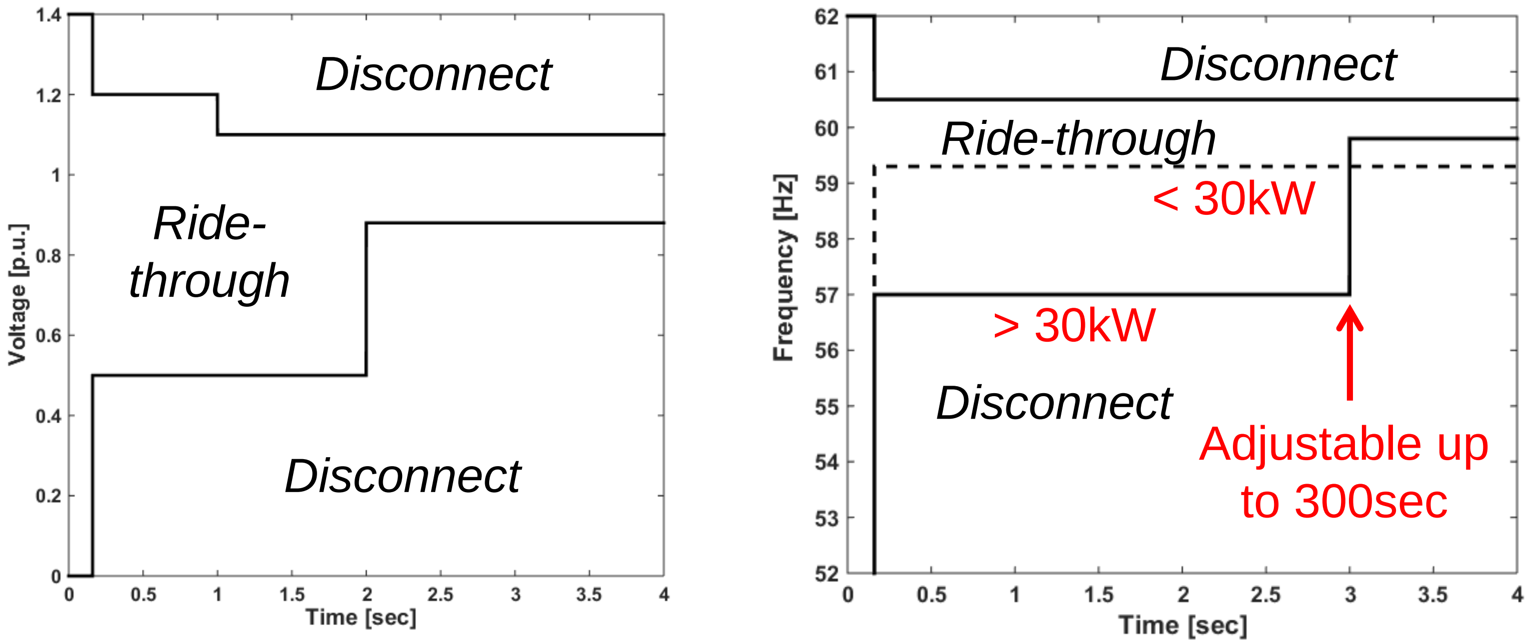


Control and measurement use LabView: This is a Screen Shot

Fault Sequences Under Study

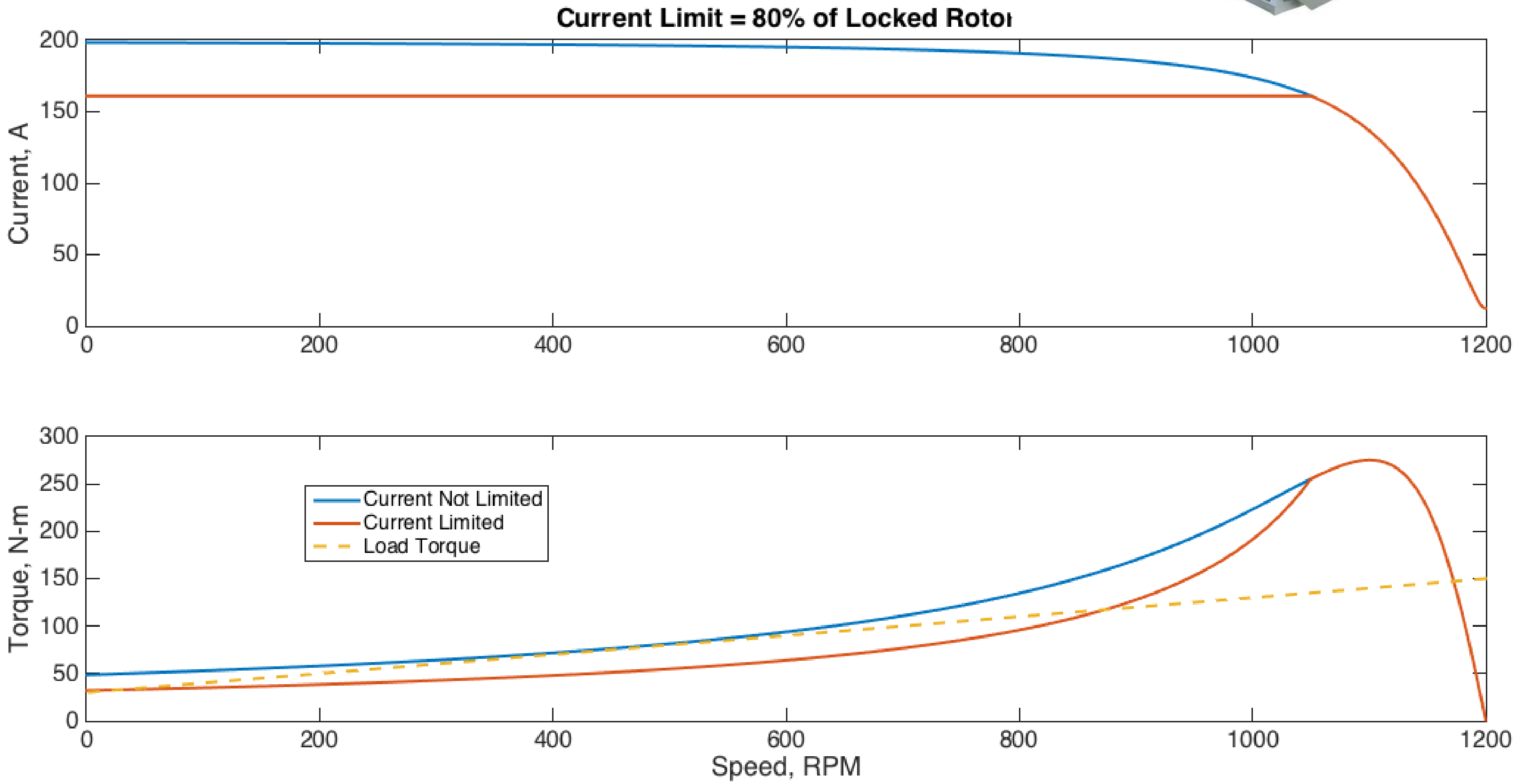


IEEE Fault-Ride Recommendation



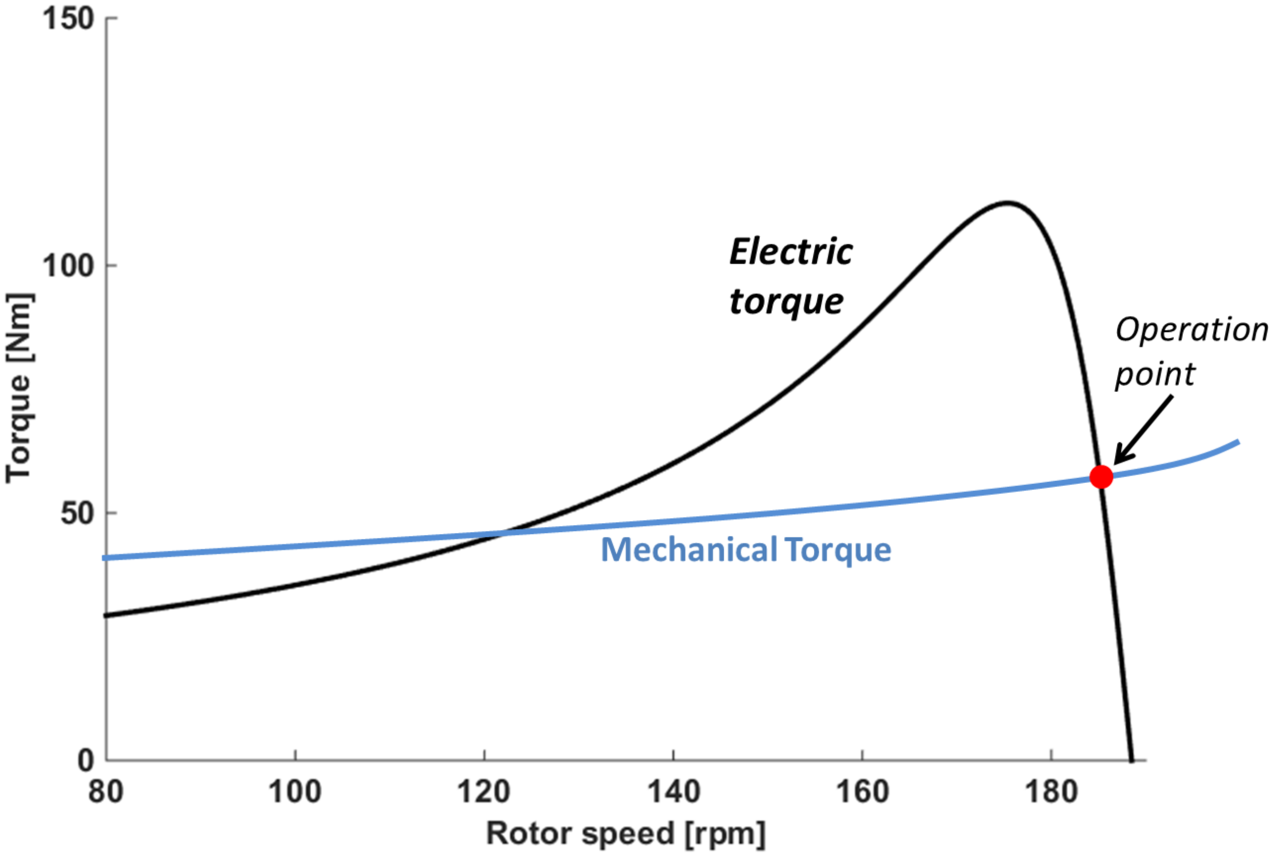
Consider an induction motor, torque and current vs. speed

If current limited, torque is reduced over part of the speed range



Pre-fault

Torque-speed curve

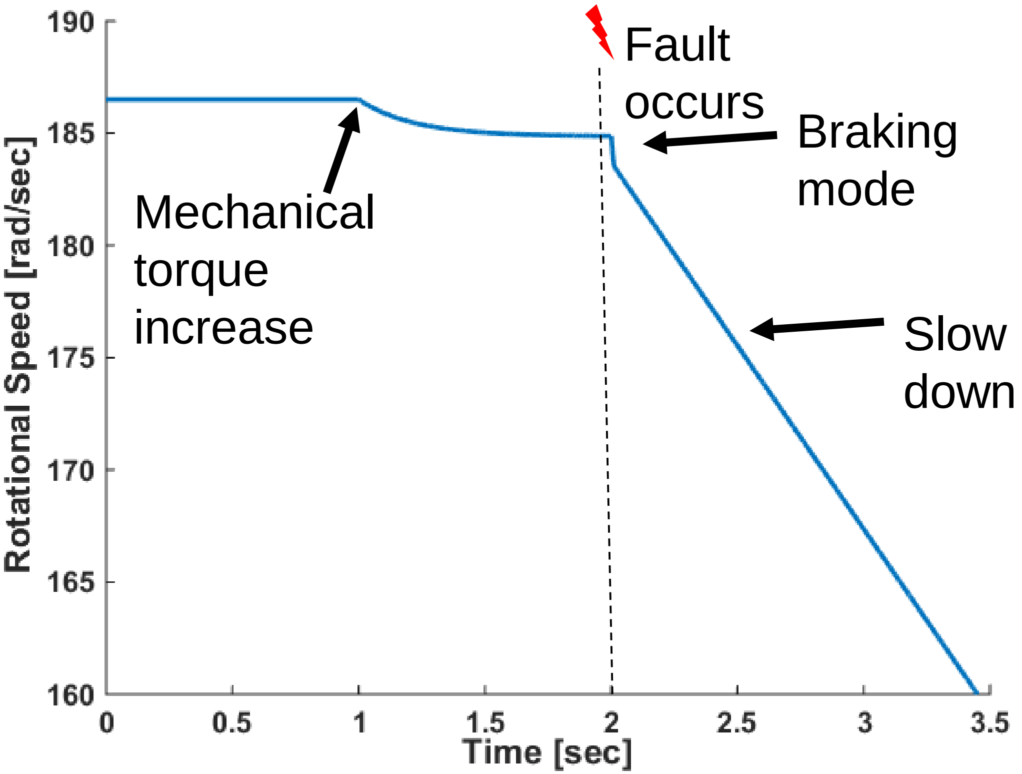


Intersection of the mechanical and electrical torques gives the operation point

During fault

At the moment of the fault, two phenomena occur:

1. Braking mode – IM dissipates its trapped flux
2. Slow down due to mechanical torque



Detail of Simulation during a fault

Dynamics

Electrical dynamics

$$\frac{d}{dt}\lambda_{ds} = v_d + \omega_0\lambda_{qs} - R_s i_{ds}$$

$$\frac{d}{dt}\lambda_{qs} = v_q - \omega_0\lambda_{ds} - R_s i_{qs}$$

$$\frac{d}{dt}\lambda_{dr} = (\omega_r - \omega_0)\lambda_{qr} - R_r i_{dr}$$

$$\frac{d}{dt}\lambda_{qr} = -(\omega_r - \omega_0)\lambda_{dr} - R_r i_{qr}$$

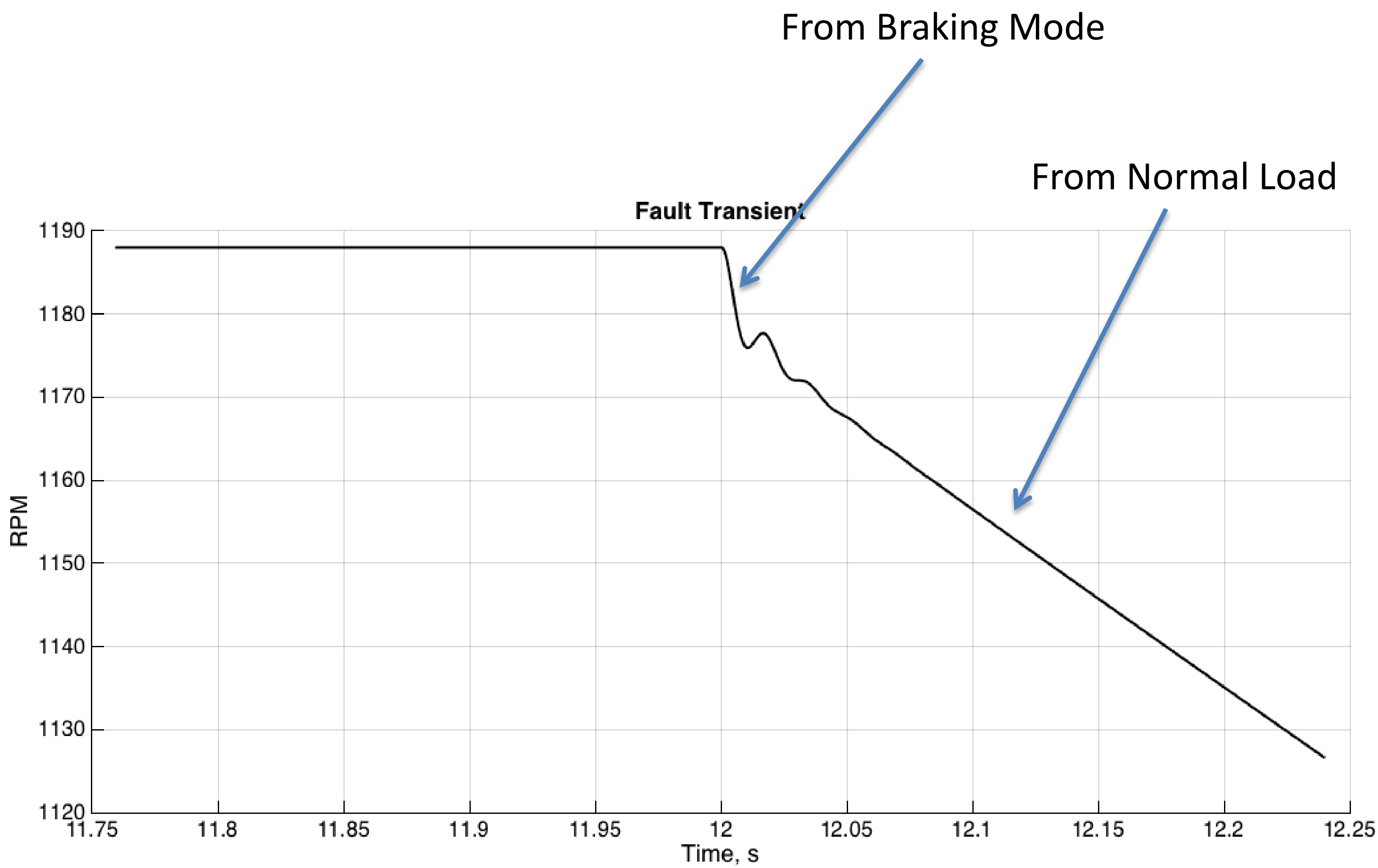
Mechanical dynamics

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - T_m - F\omega_r)$$

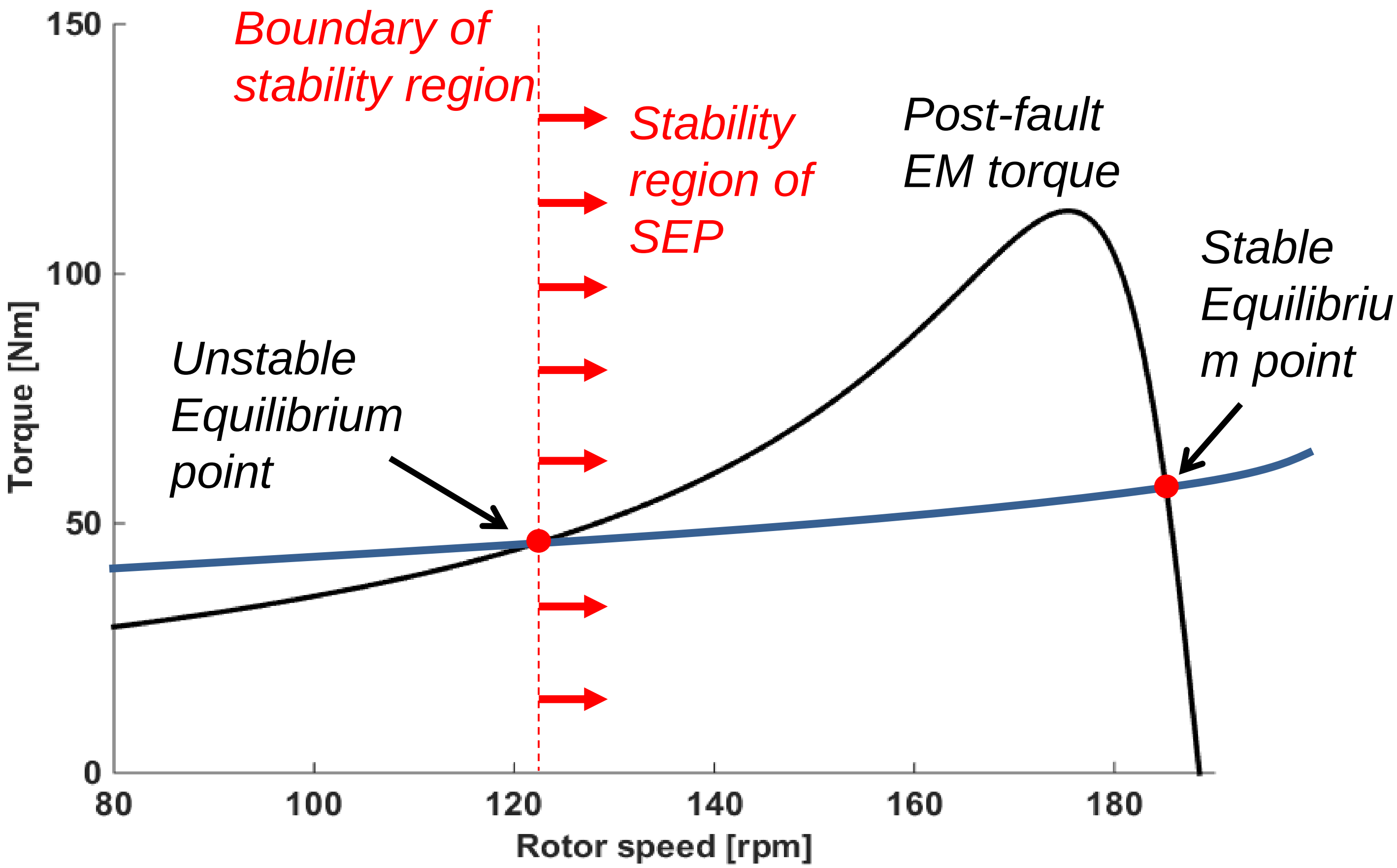
$$T_e = \frac{3}{2}p\left(\lambda_{ds}i_{qs} - \lambda_{qs}i_{ds}\right)$$

T_m depends on the mechanical load

Detail of simulation of Induction Motor Fault Behavior

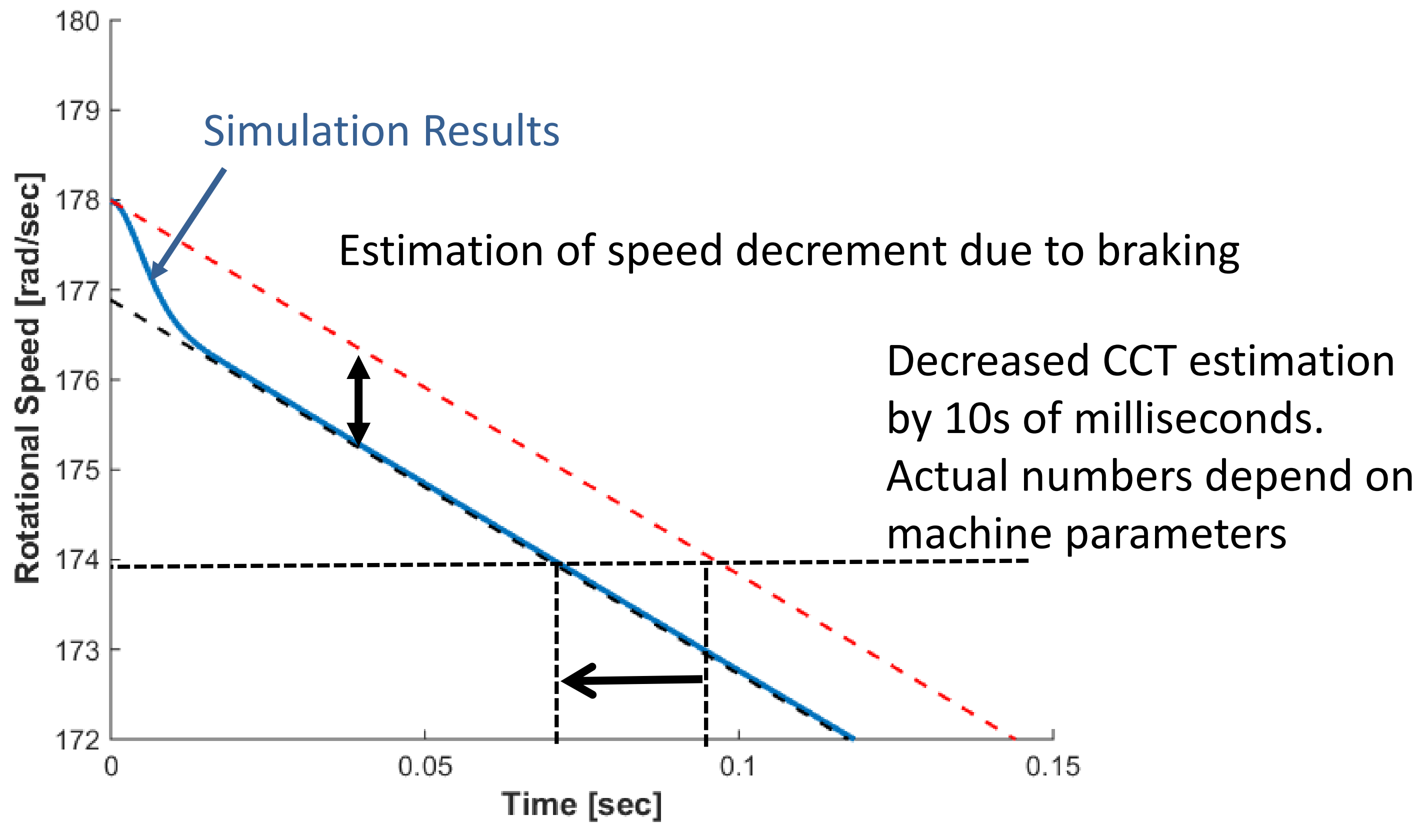


After the fault, the IM has electromagnetic torque returns



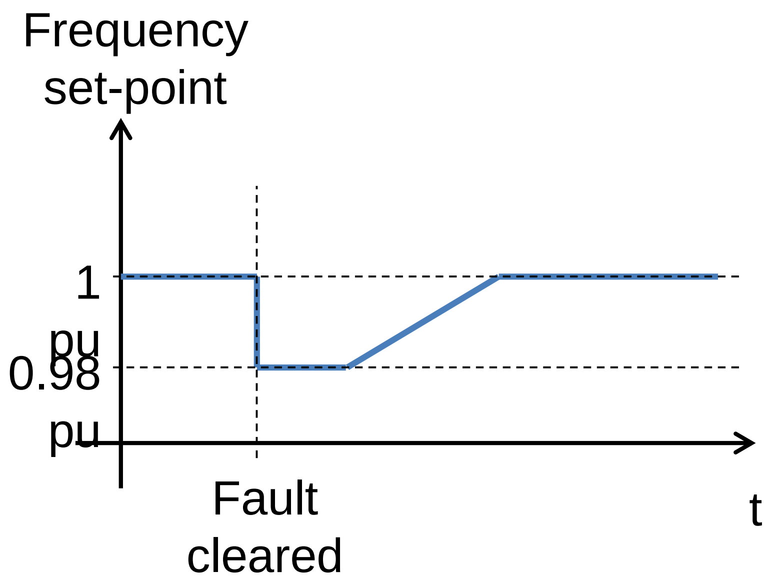
Braking Mode Analysis

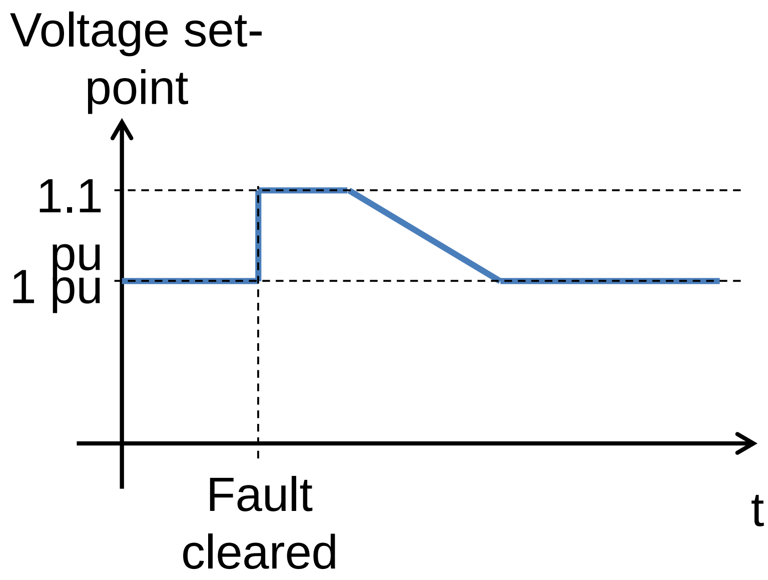
Method gives a good estimation of real speed decay



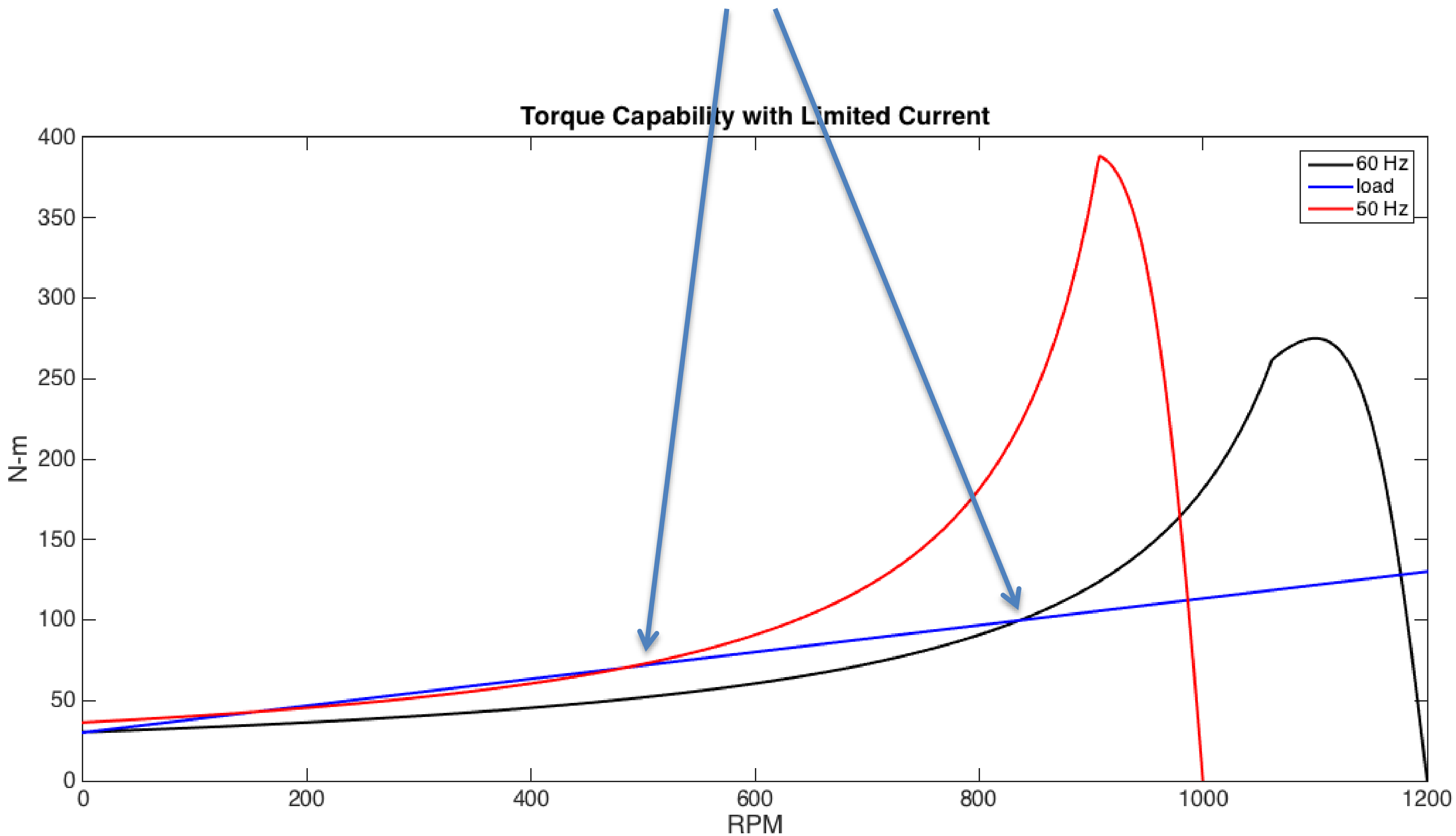
Proposed Control Method
Take Advantage of the inverter
Can Adjust Frequency and Voltage

Challenge the paradigm that a system has to recover to nominal conditions
Instead, recover to "advantageous" conditions:

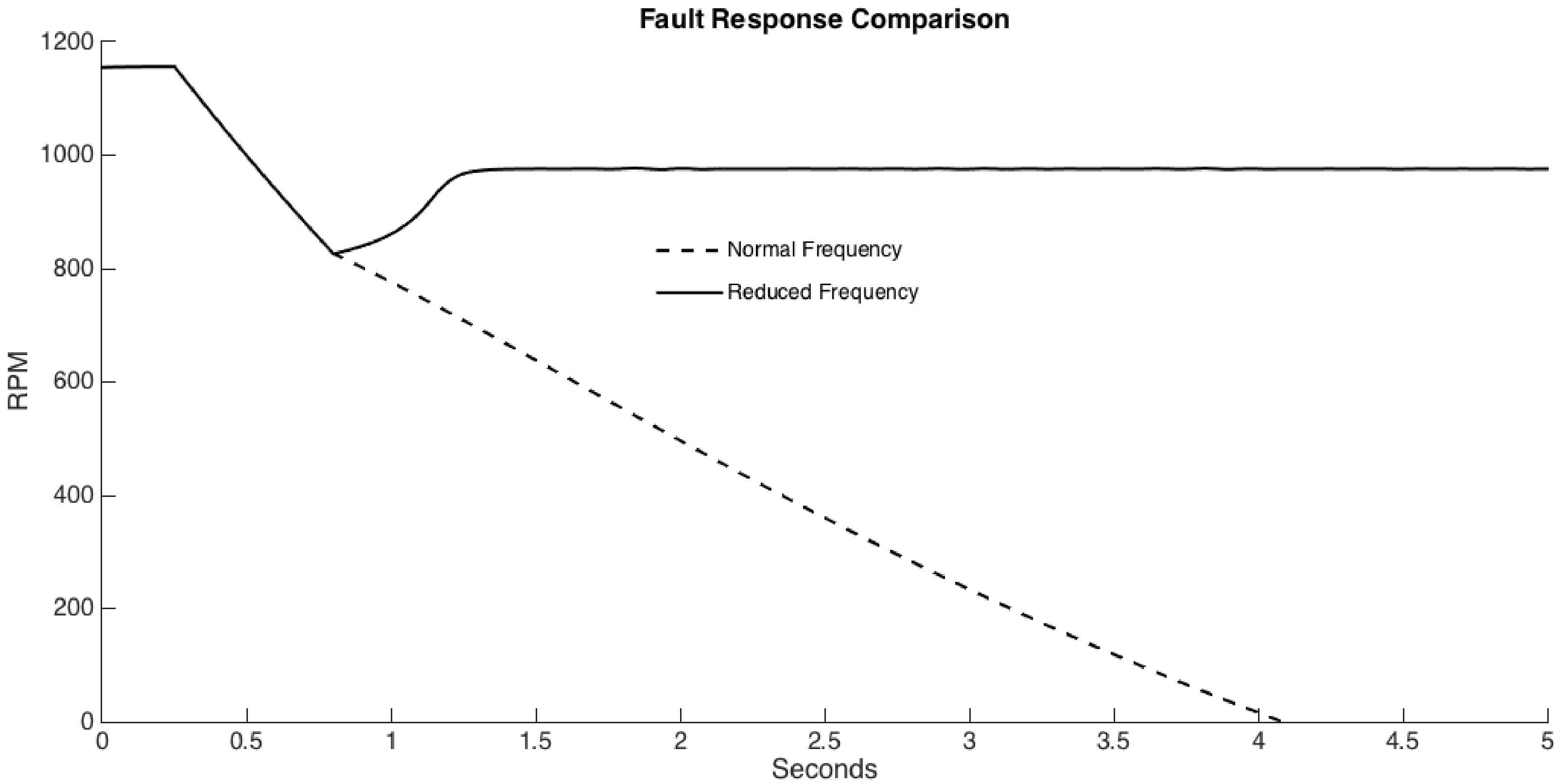




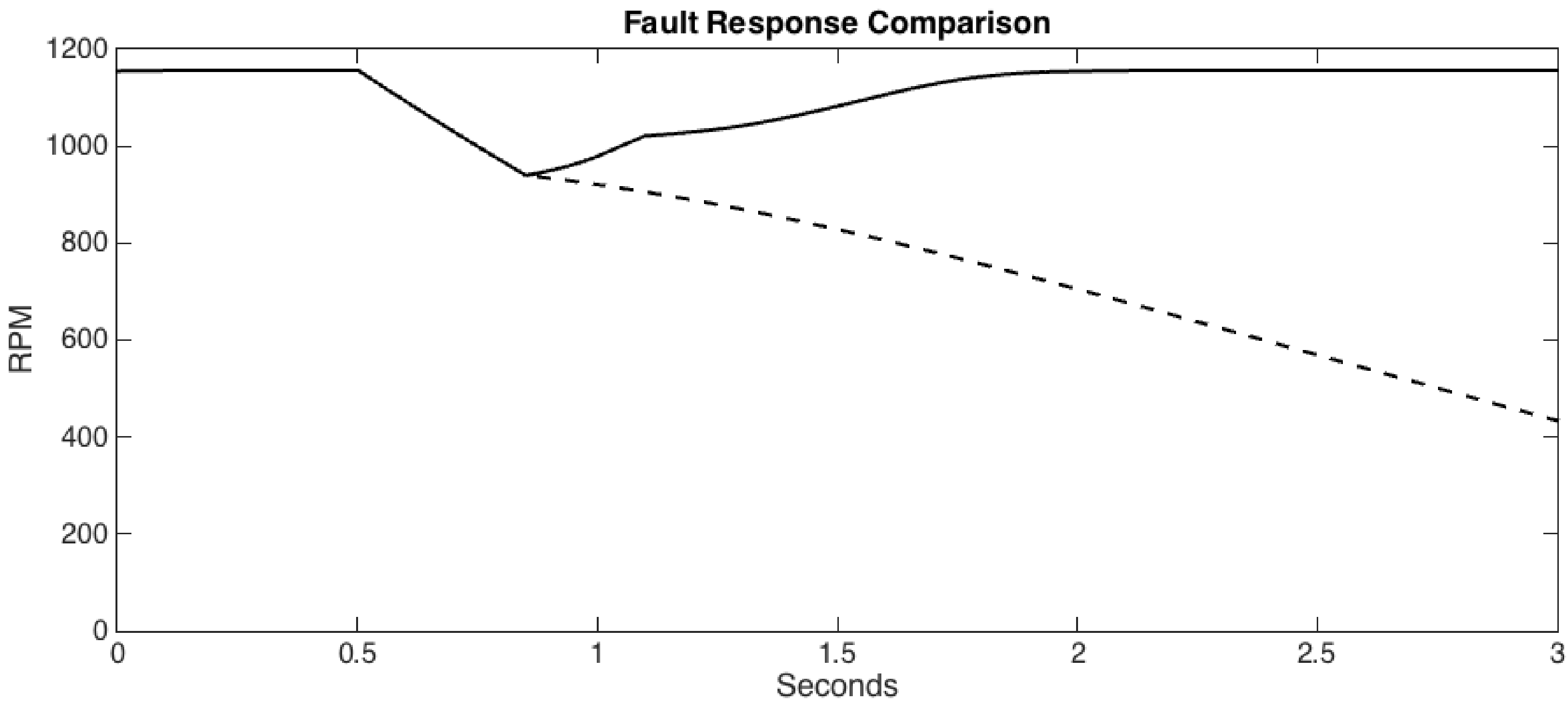
Effect of Frequency Reduction
Current Limited Conditions
Difference in Clearing Time



Simulation of a Cleared Fault Recovery

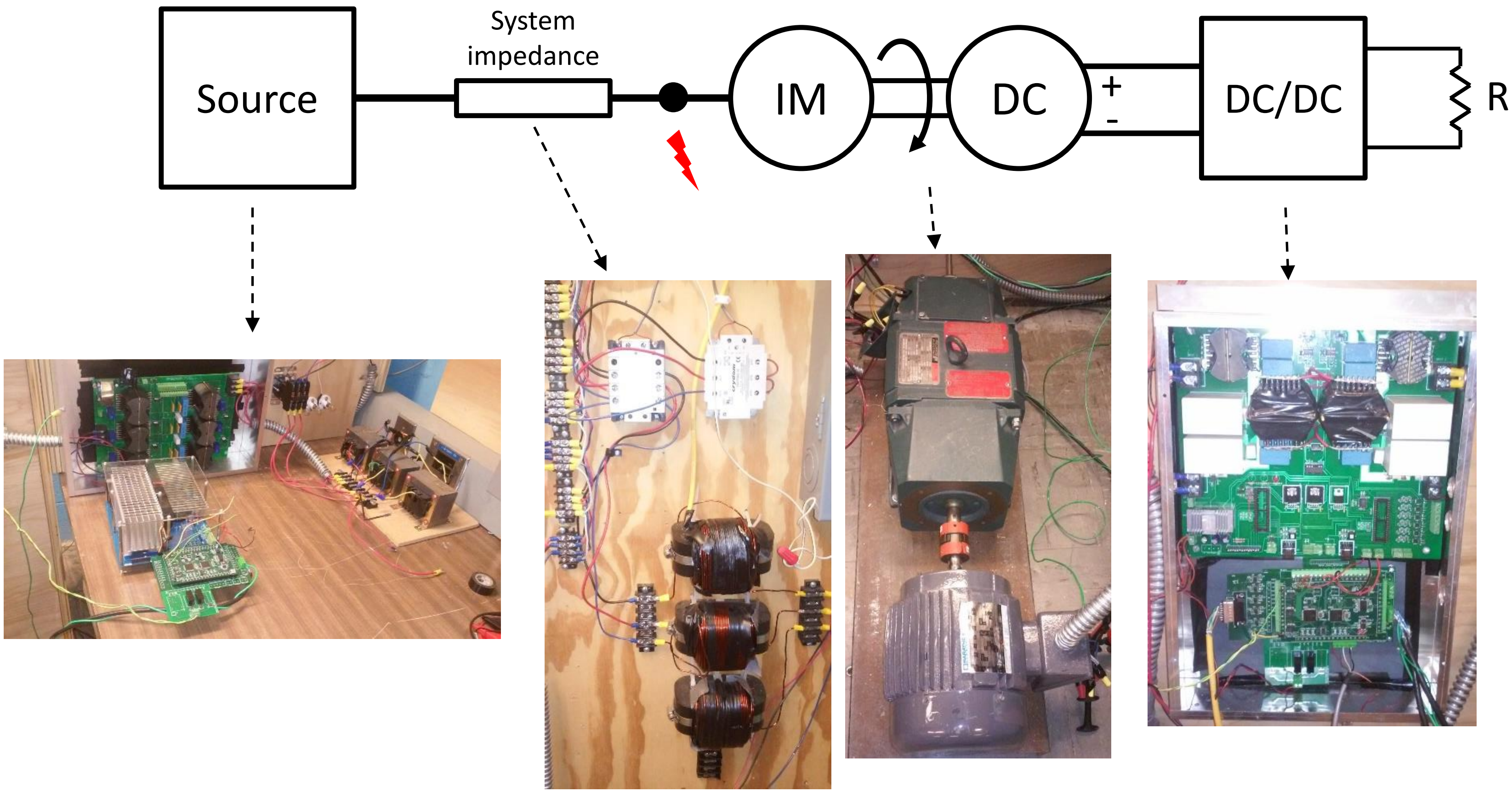


Or with a fairly rapid return to normal frequency

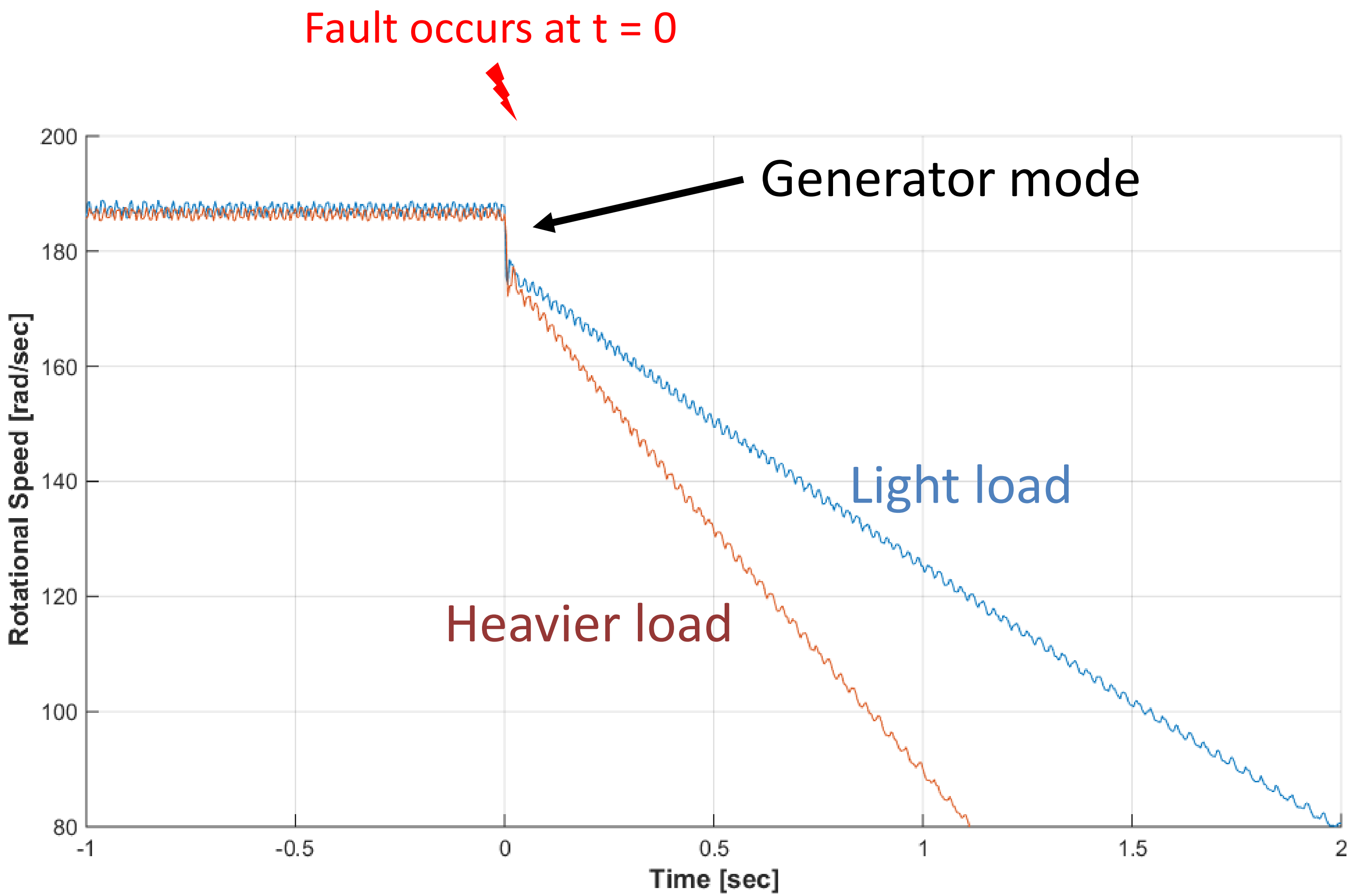


Experimental Results

Microgrid Experimental set-up

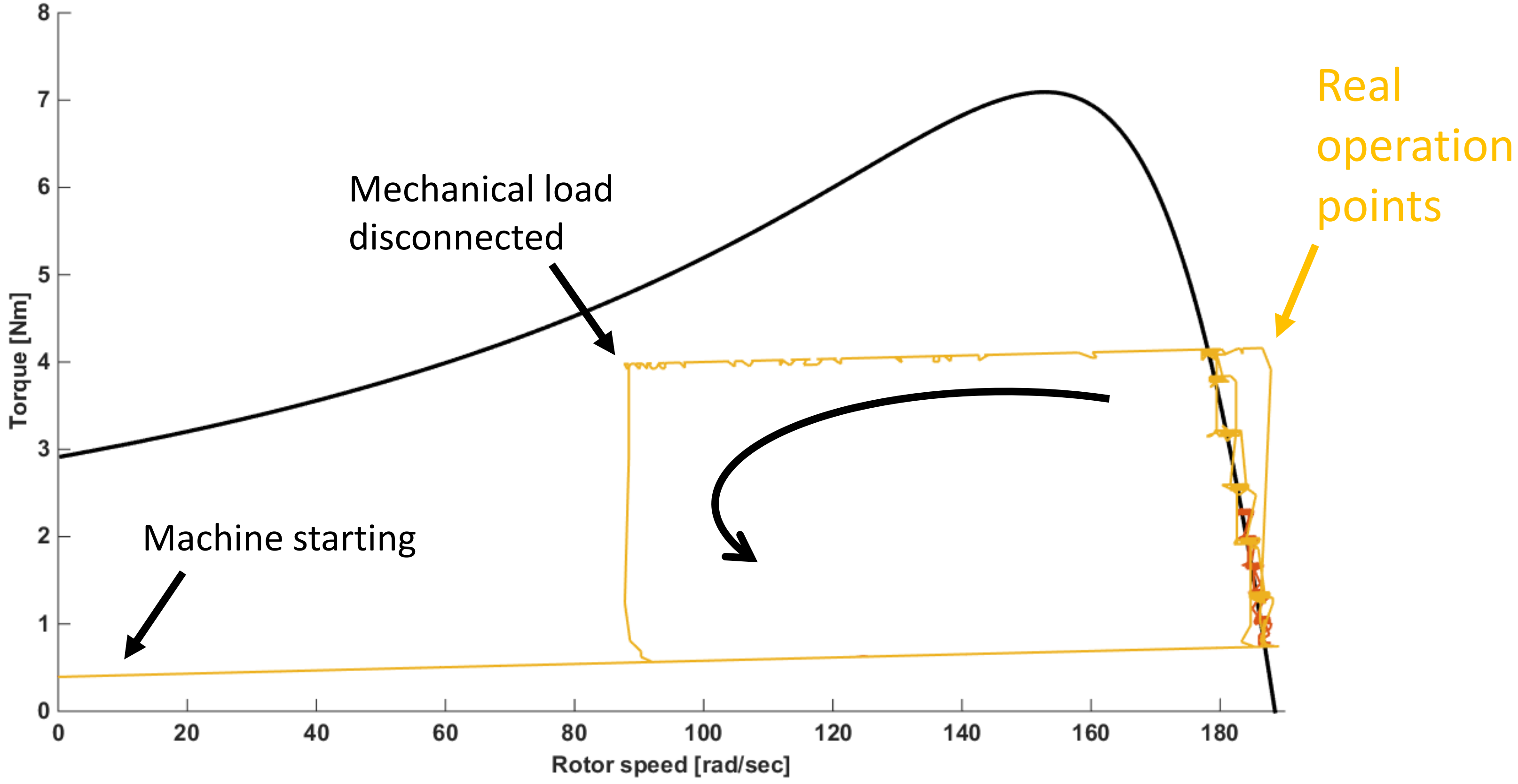


Dynamics after the fault

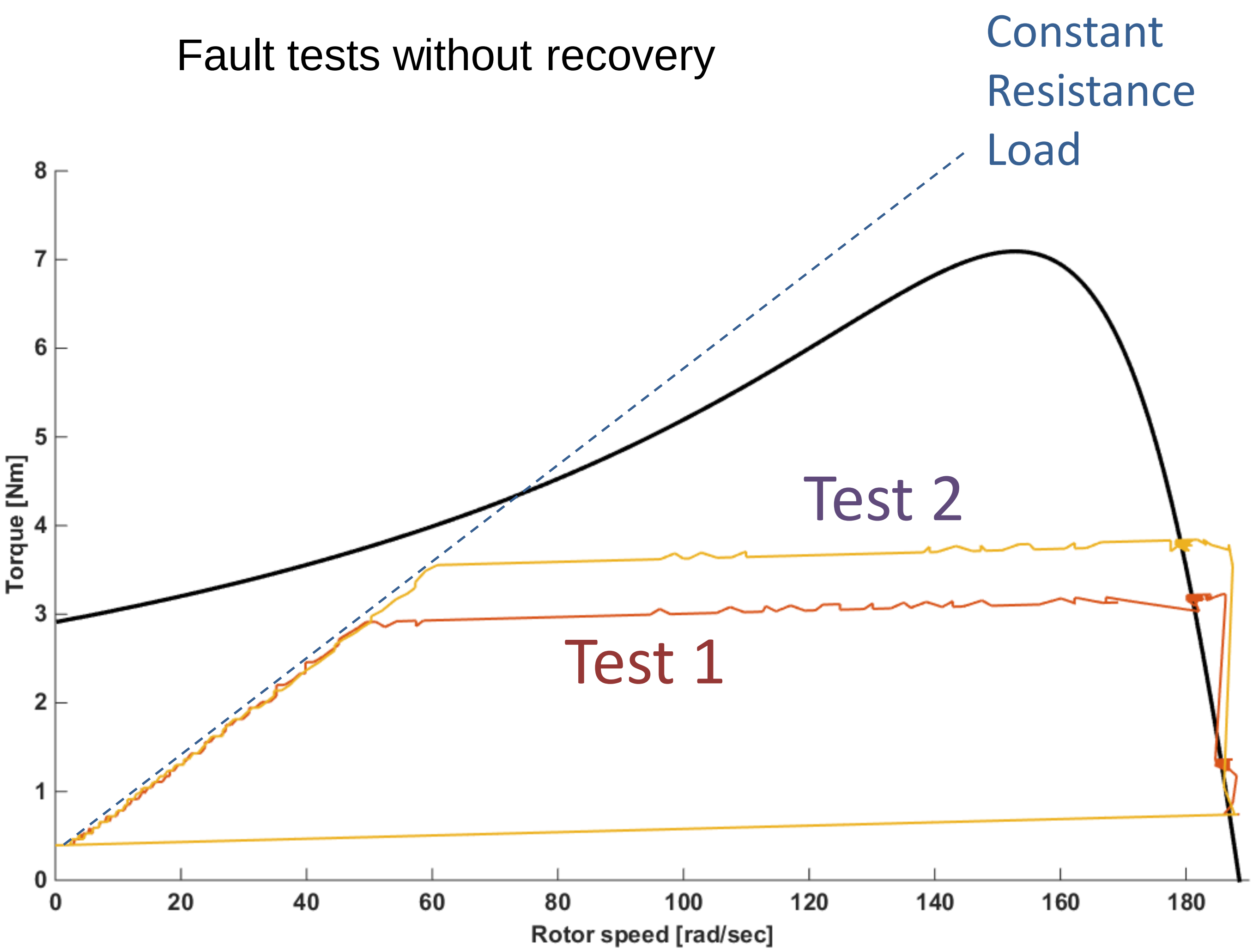


Experimental Results

To validate the torque-speed curve, we did a load change experiment

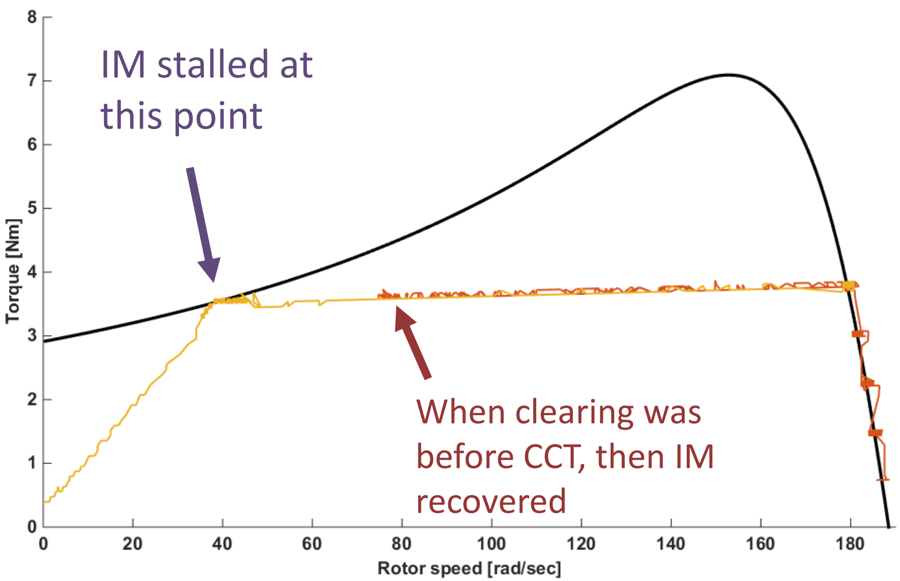


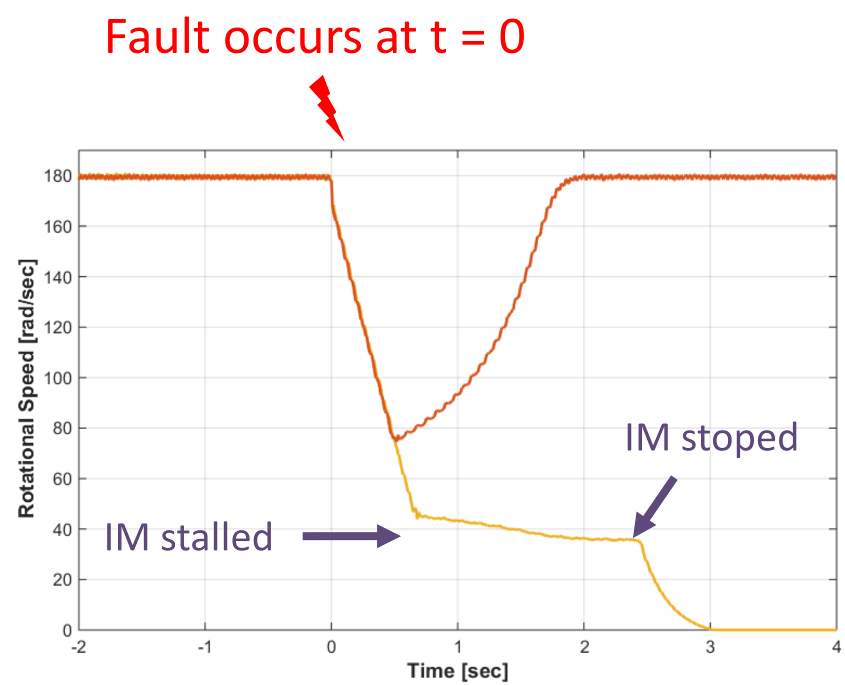
Experimental Results



Experimental Results

Fault tests with recovery



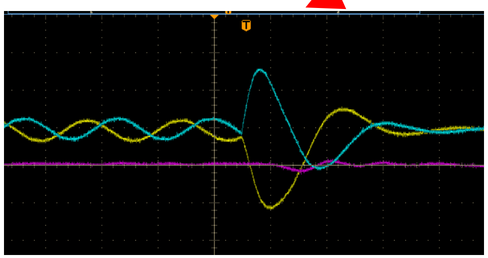


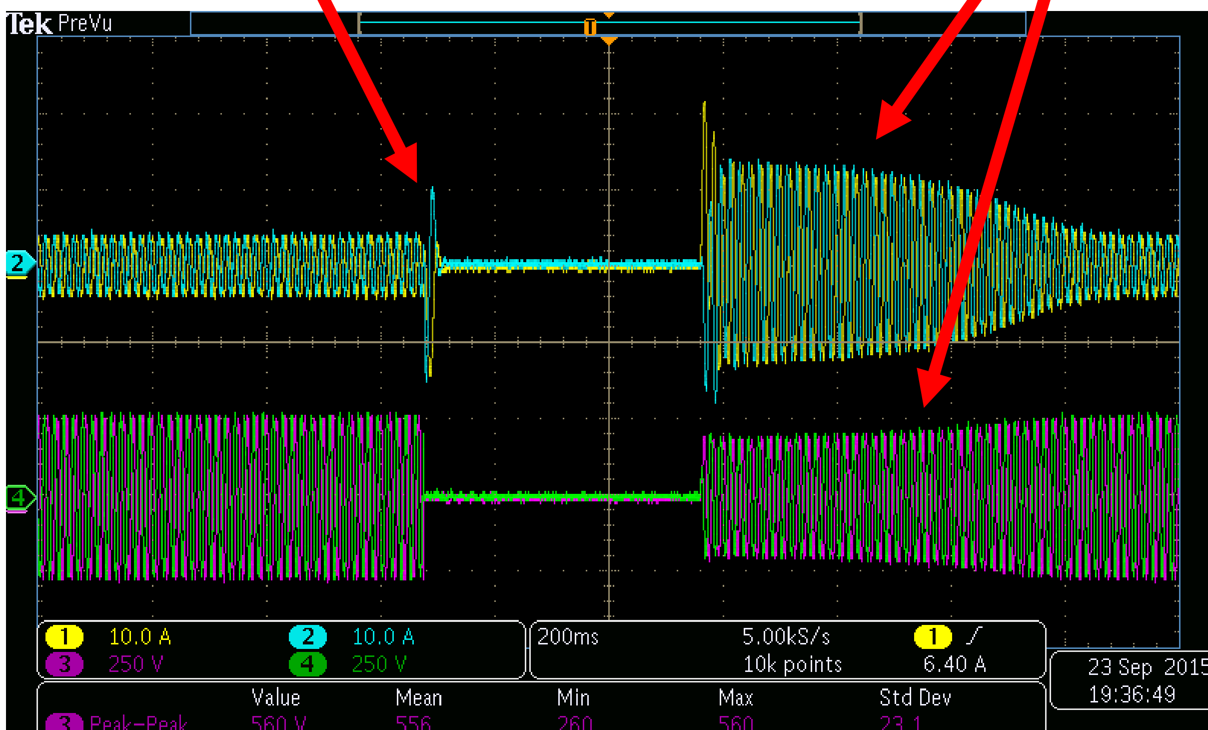
Experimental Results

Fault tests with recovery

Current peak during generator mode

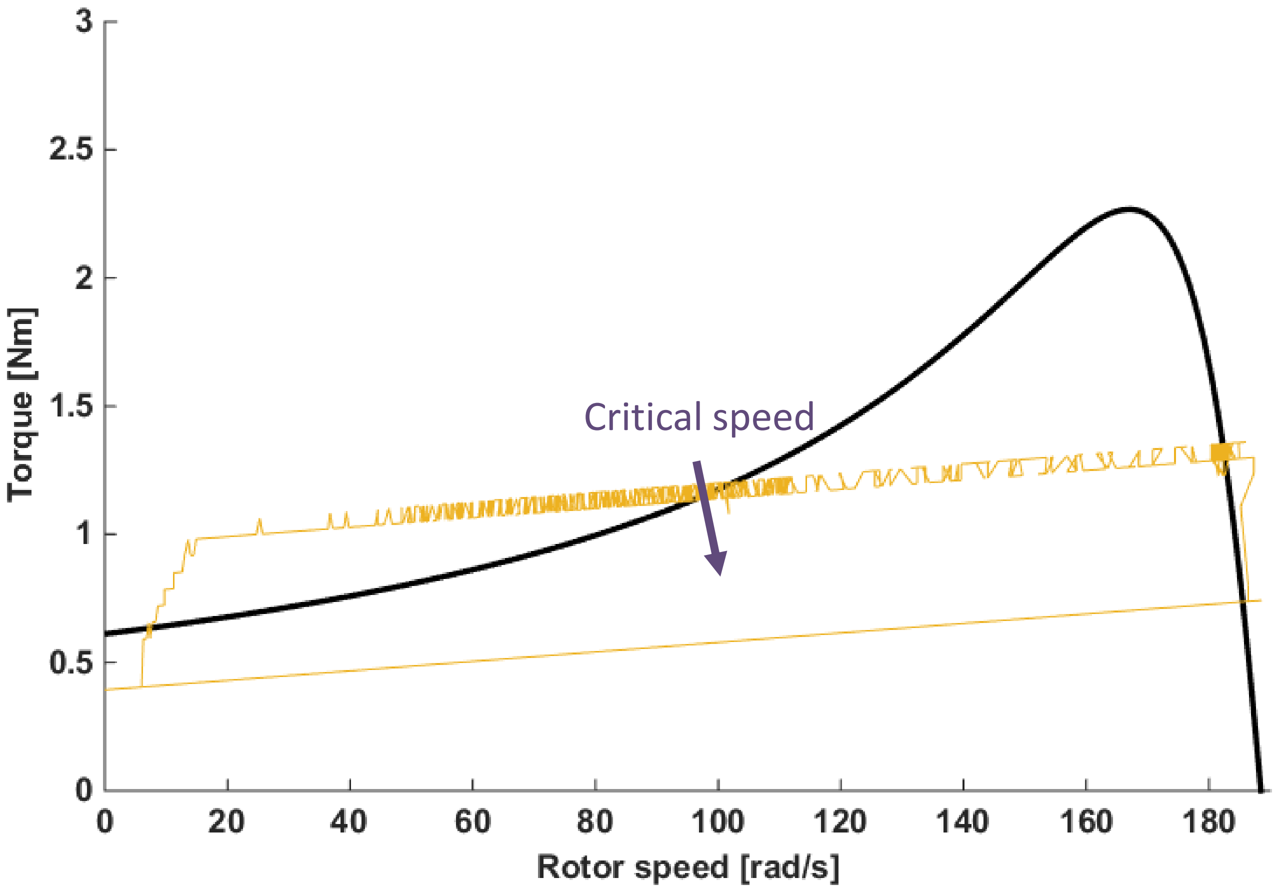
During recovery, large currents are observed, and voltage is low





Experimental Results

Inverter as source



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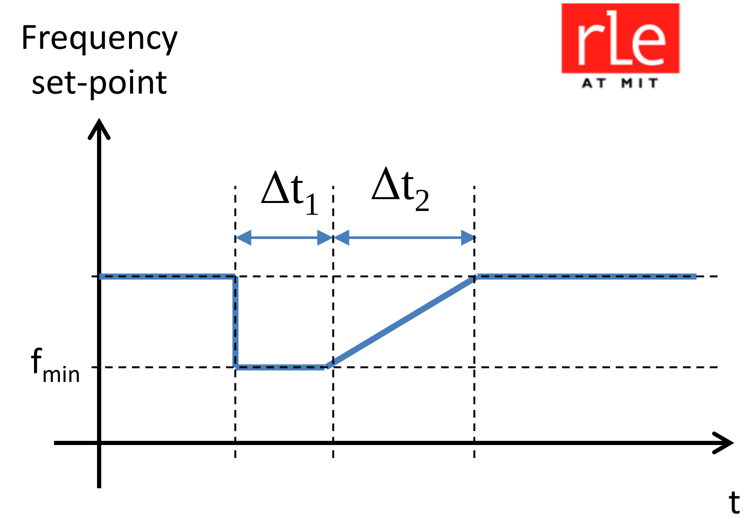

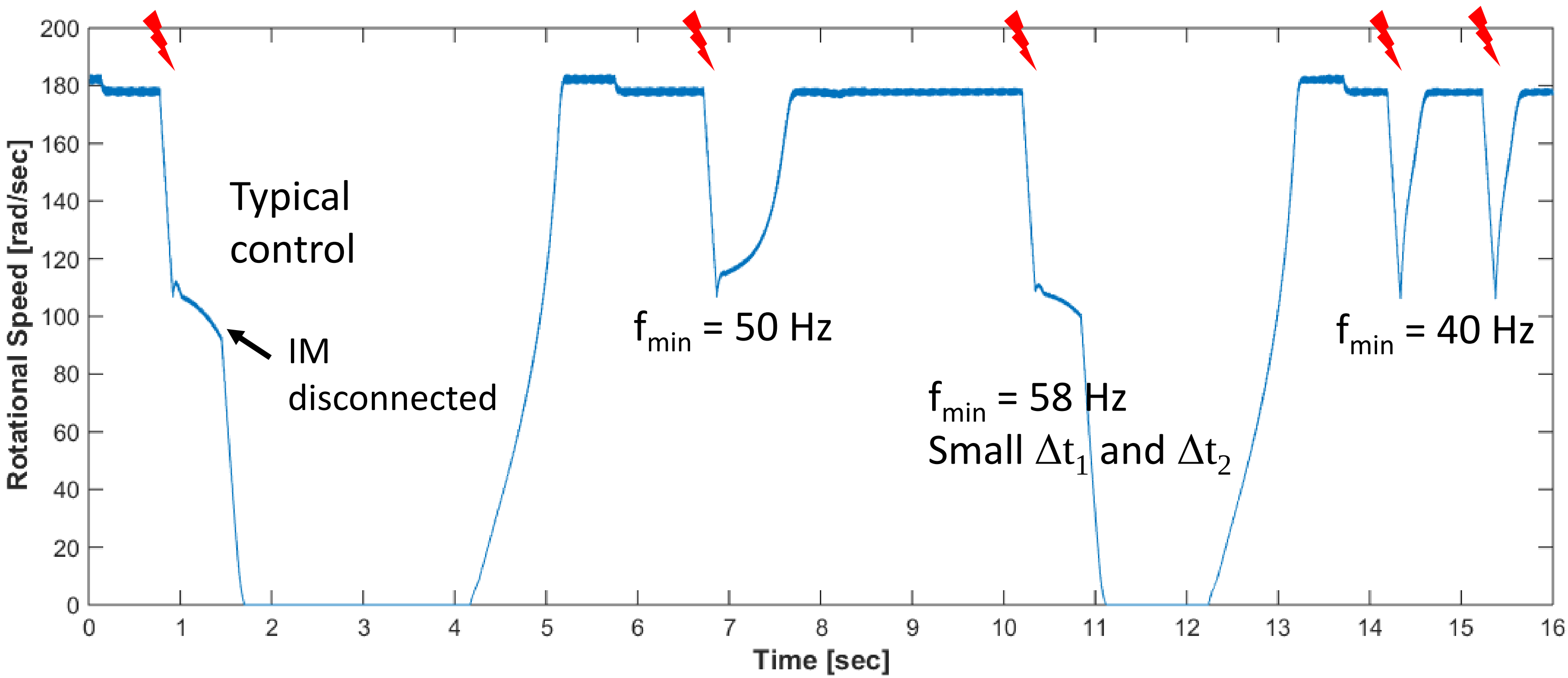

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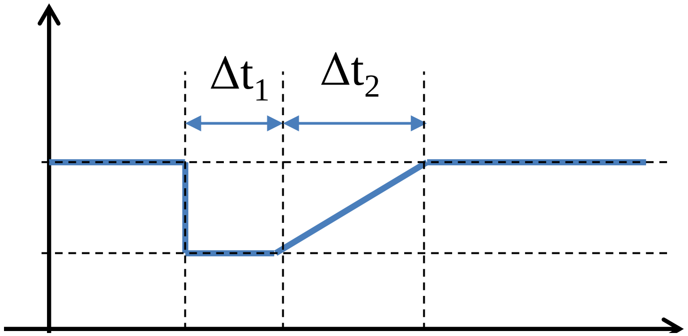

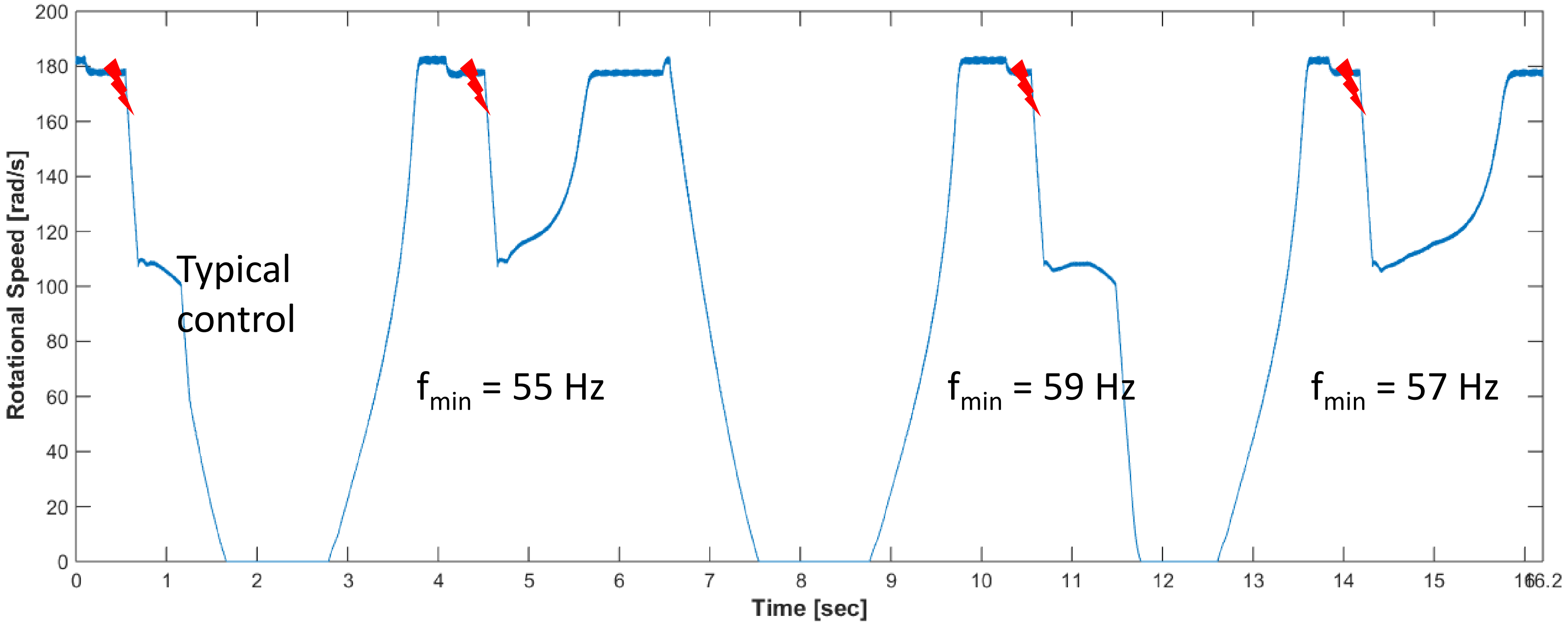

Conclusions

- Induction Motor (IM) are a significant fraction of loads in power systems and microgrids
- IM can stall leading to voltage collapse or load shedding
- Direct methods can be applied to calculate the CCT from machine parameters and initial conditions – *no need of time-domain simulations*
- A control strategy was proposed to increase the CCT and improve recovery
- Experimental results validate the above points