SOUTHERN COMPANY *Transmission*

Assessment of Fault Induced Delayed Voltage Recovery – Load Modeling Impacts

U.S. Department of Energy Workshop

Dallas, Texas

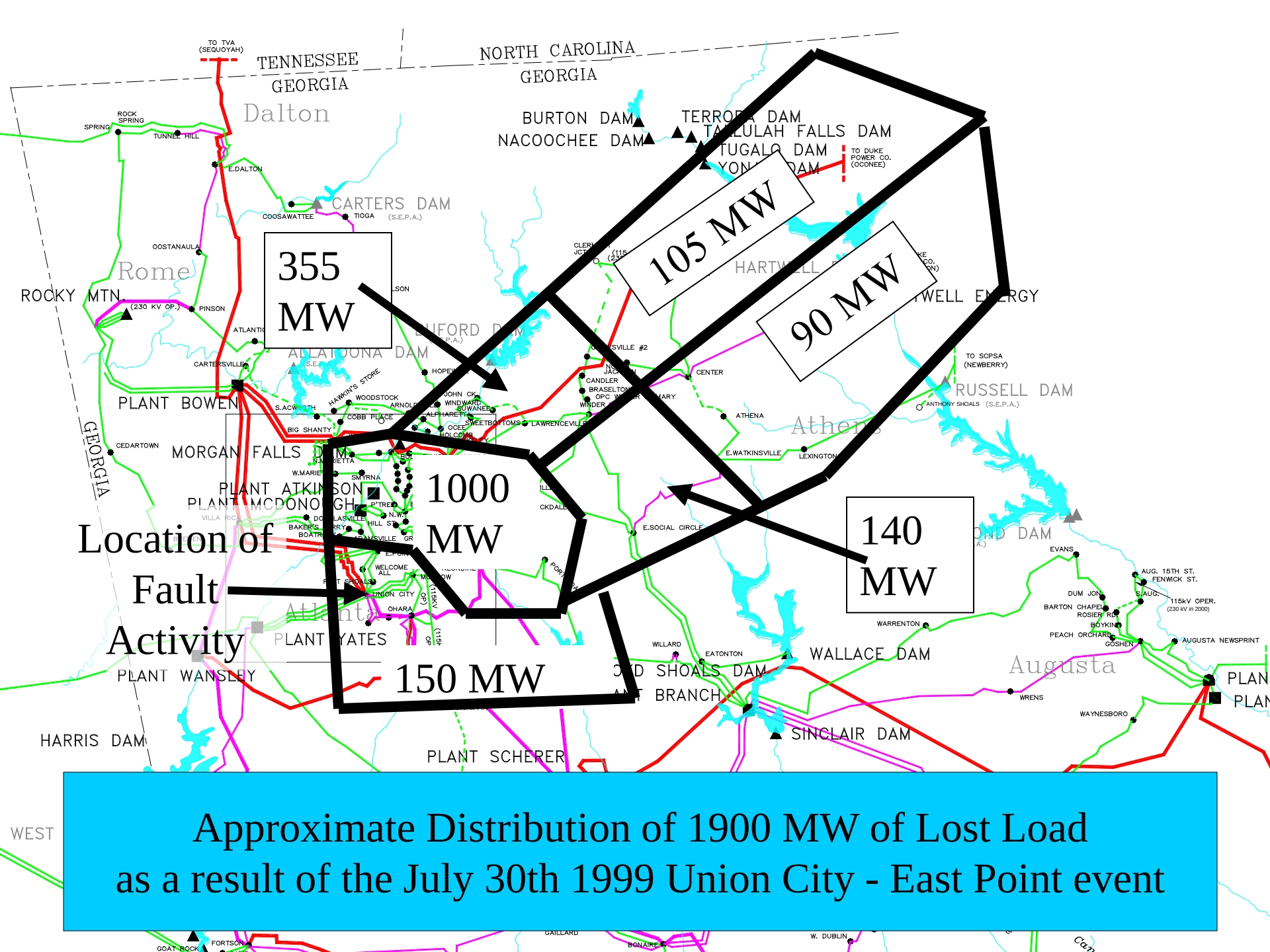
April 22, 2008

SOUTHERN COMPANY

Energy to Serve Your World®

Outline

- Development of Load Model used in FIDVR Exposure Assessments
  - Steady State vs. Dynamic Analysis
  - Load Model development per event re-construction
  - Future Load Model refinements
- Questions / Discussion



Approximate Distribution of 1900 MW of Lost Load
as a result of the July 30th 1999 Union City - East Point event

Aggregate Load Model Development

- Motivation to replicate the Union City event so that exposure for more probable events could be assessed.
- Steady state load flow evaluations are used for the majority of Transmission Planning evaluations. Characteristics include:
  - A “snap shot” in time evaluation
  - Short term dynamics of generators, exciters, governors, and loads are ignored
  - Key results include steady state power flows and voltage levels

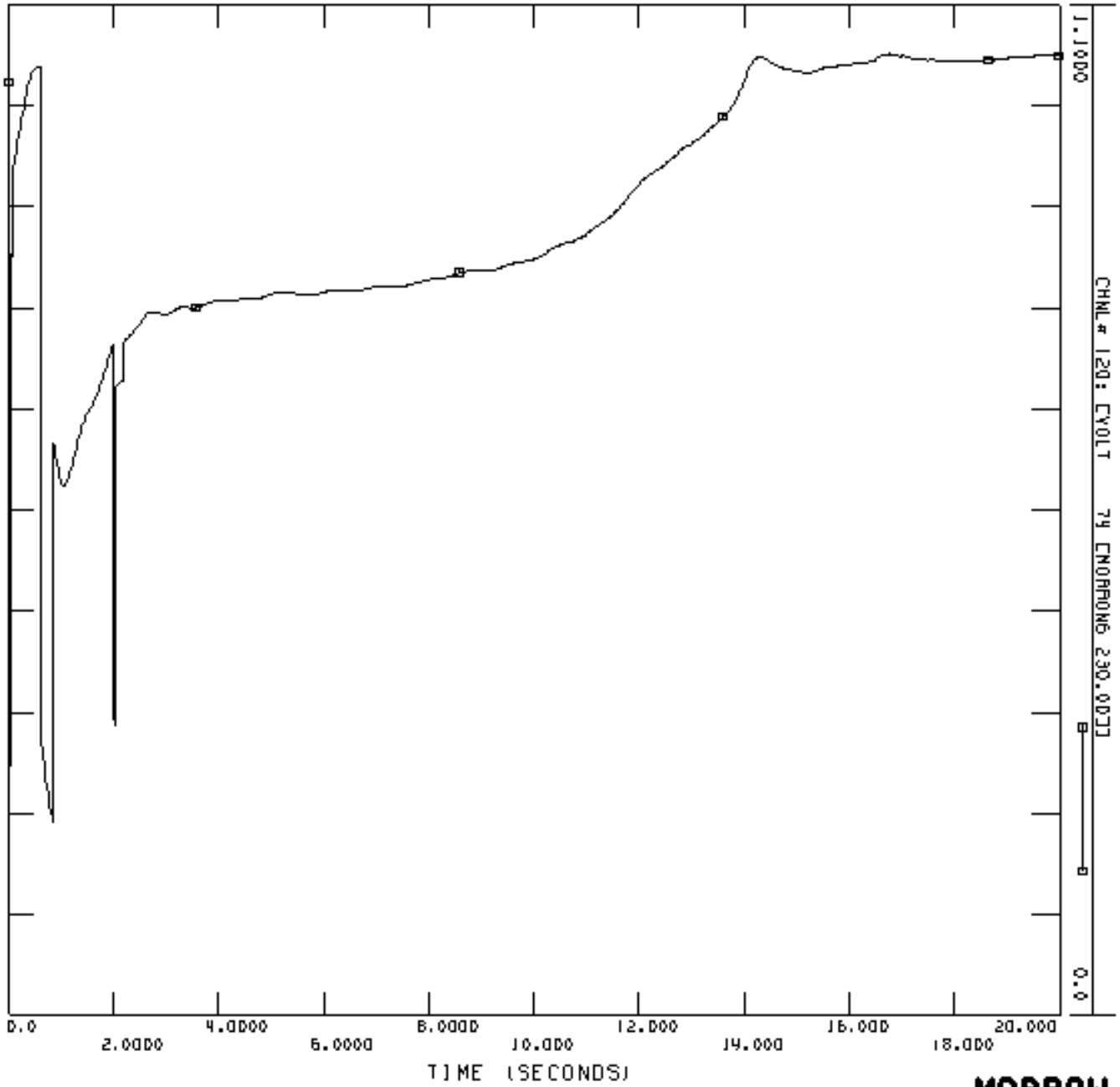
Aggregate Load Model Development

- Steady state load flow evaluations are not suited for FIDVR assessments
  - Induction motor loads, when presented low enough voltages, slow down and result in increased loadings at degraded power factors
  - Unit response to low voltages are based in part on excitation system dynamics
  - Thus, load and unit dynamics over time have to be considered in order to assess if / when transmission system voltage recovers
    - Steady state evaluations with a single “snapshot in time” result are insufficient

Aggregate Load Model Development

- Dynamic Simulation are required to evaluate FIDVR events
  - Dynamic simulation programs include, in part, generator, exciter, governor, and load models represented by sets of differential equations
  - Numerical techniques are utilized to solve differential equations at discrete time steps
  - Results are power system quantities over a period of time
  - The modeling of loads, particularly the induction motor component, is critical

Power Technologies, Inc.



STARTED FROM REDOIS.SAV WITH REDUCED Q2 EXT. BUT WITH 99
J: 7-30-99 EVENT

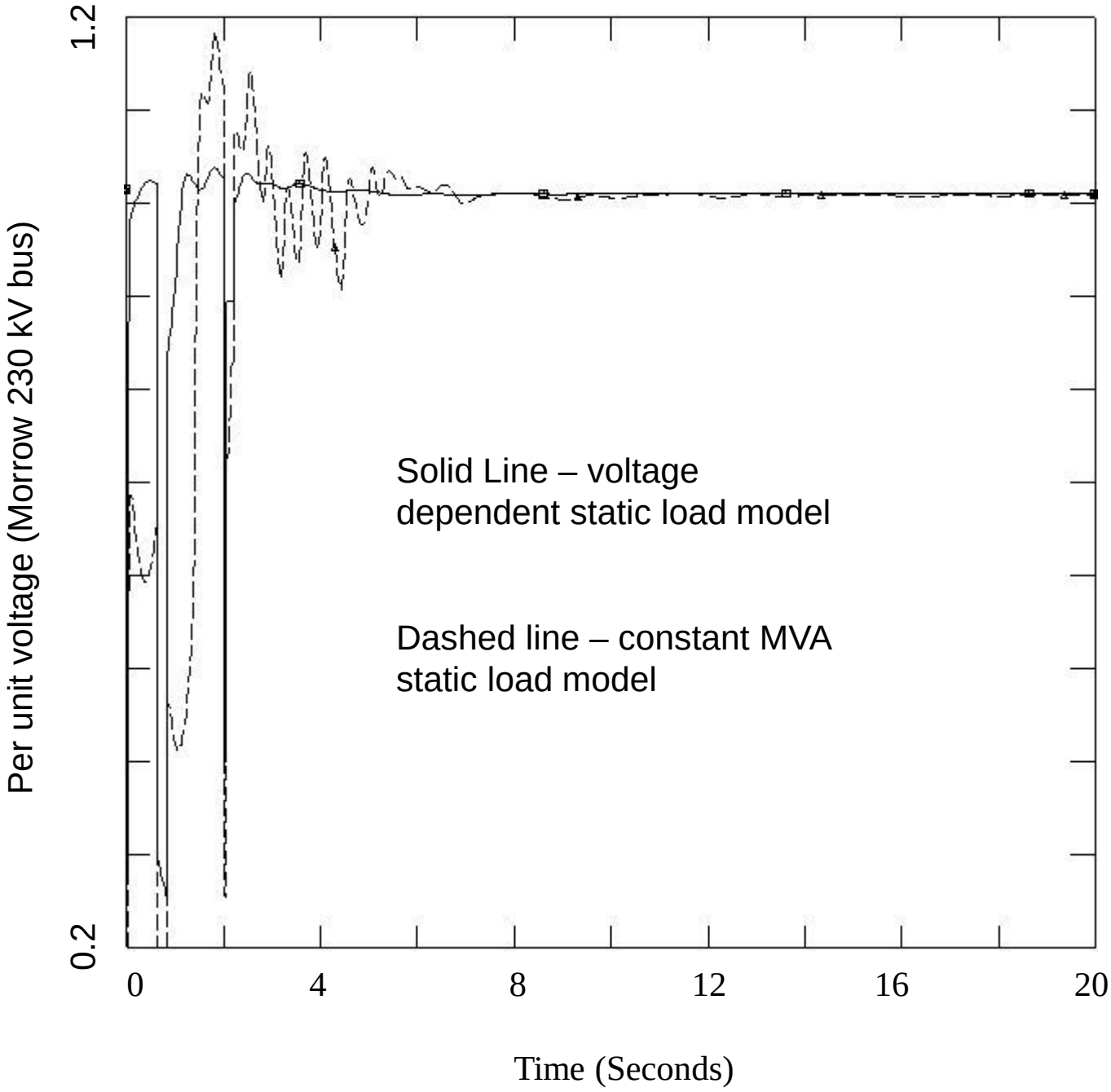
FILE: C:\WORK\d4.out

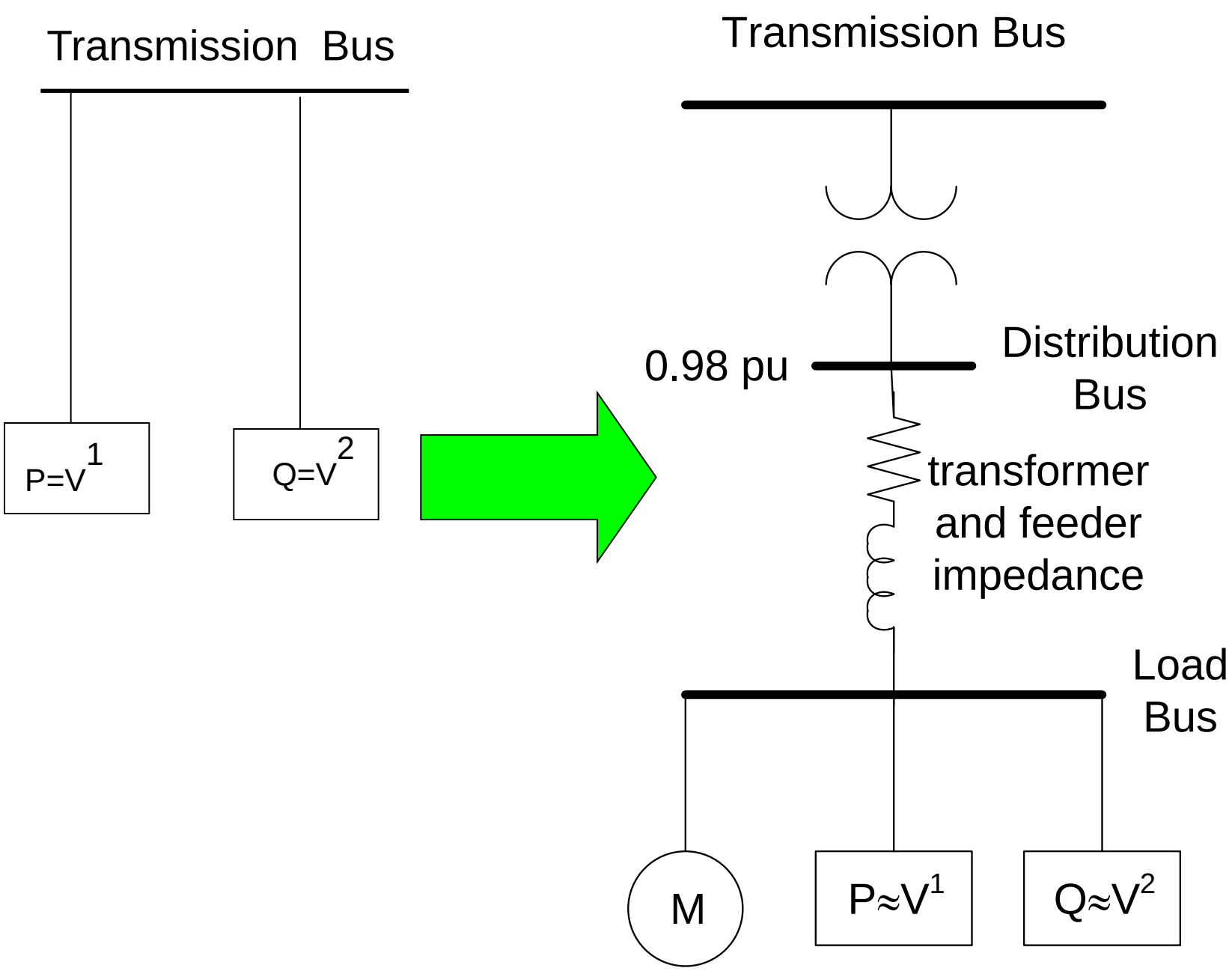
SUN. SEP 19 1999 20:13

MORROW 230 KV BUS VOLTS

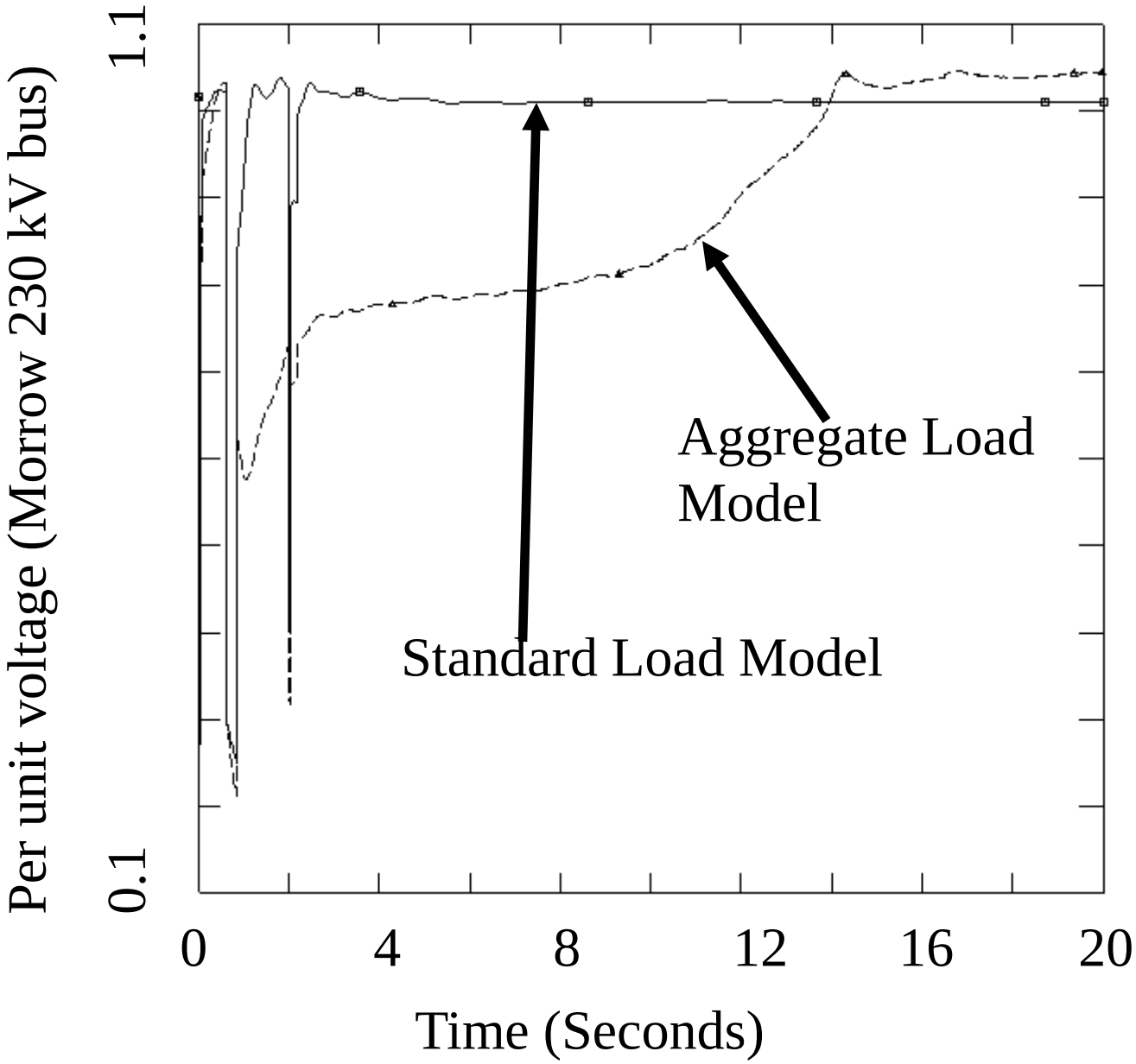
Aggregate Load Model Development

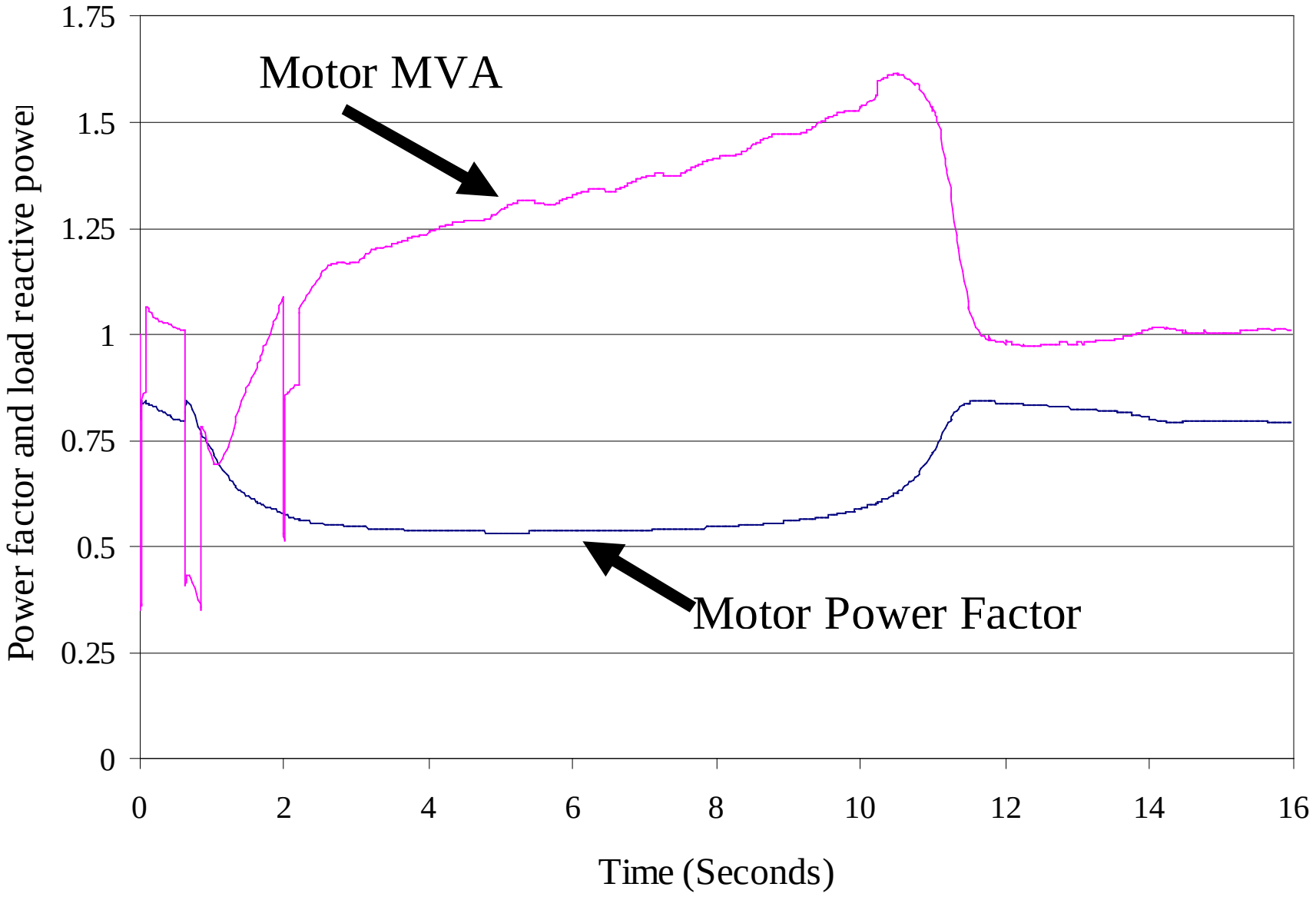
- Traditionally, dynamic simulation studies have been used to quantify exposure to unit instability
  - Constant static load model work well as large voltage deviations are, compared to FIDVR events, short in duration
    - 90% constant current, 10% constant power for Active Power
    - 100% constant impedance for Reactive Power
  - However, these load models were not appropriate for analysis of FIDVR events


1.2
0.2
Per unit voltage (Morrow 230 kV bus)
0
4
8
12
16
20
Time (Seconds)
Solid Line – voltage dependent static load model
Dashed line – constant MVA static load model


Transmission Bus
P=V^1
Q=V^2
Transmission Bus
0.98 pu
Distribution Bus
transformer and feeder impedance
Load Bus
M
P≈V^1
Q≈V^2

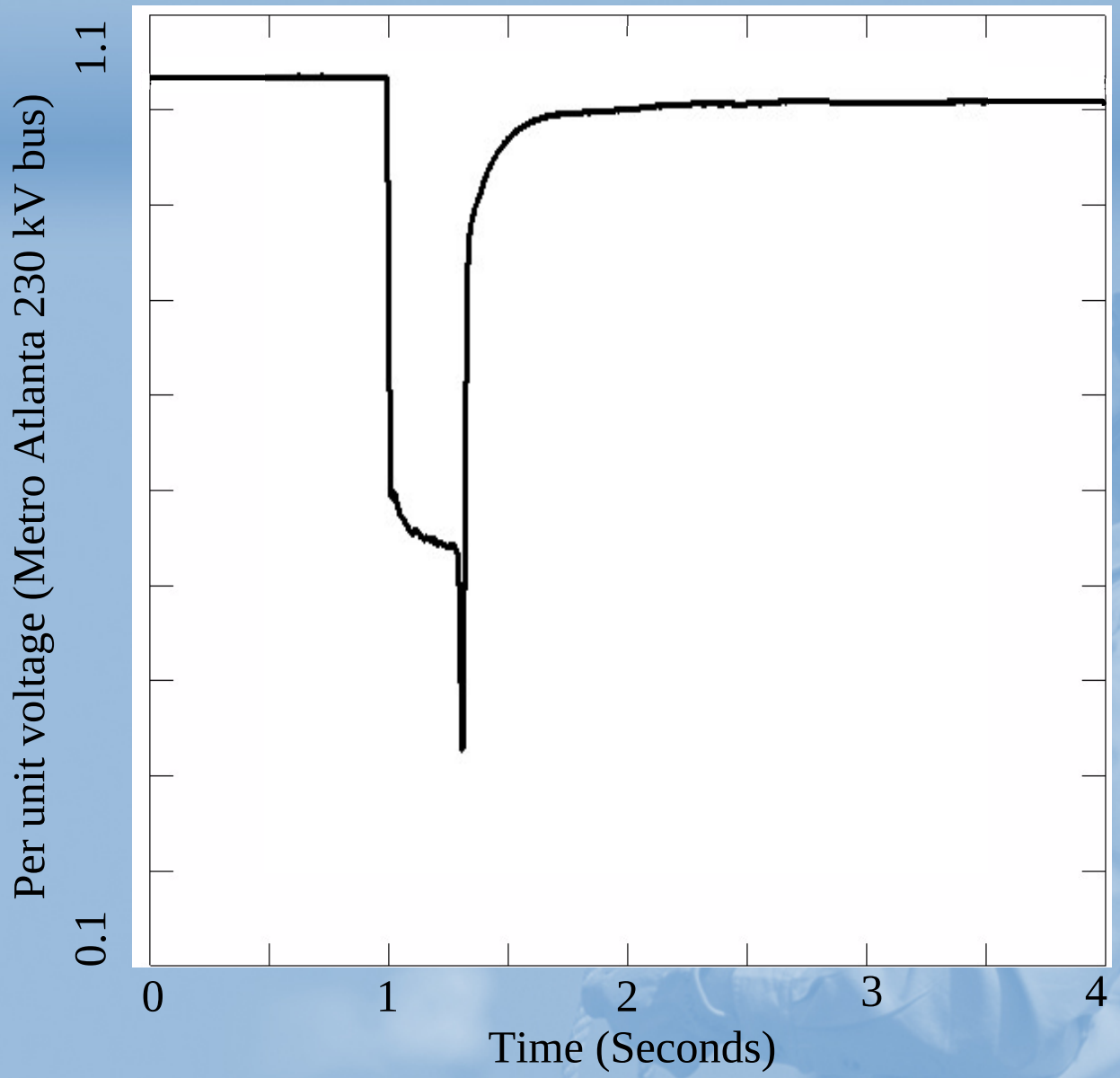
Dynamic Simulation with Different Load Models



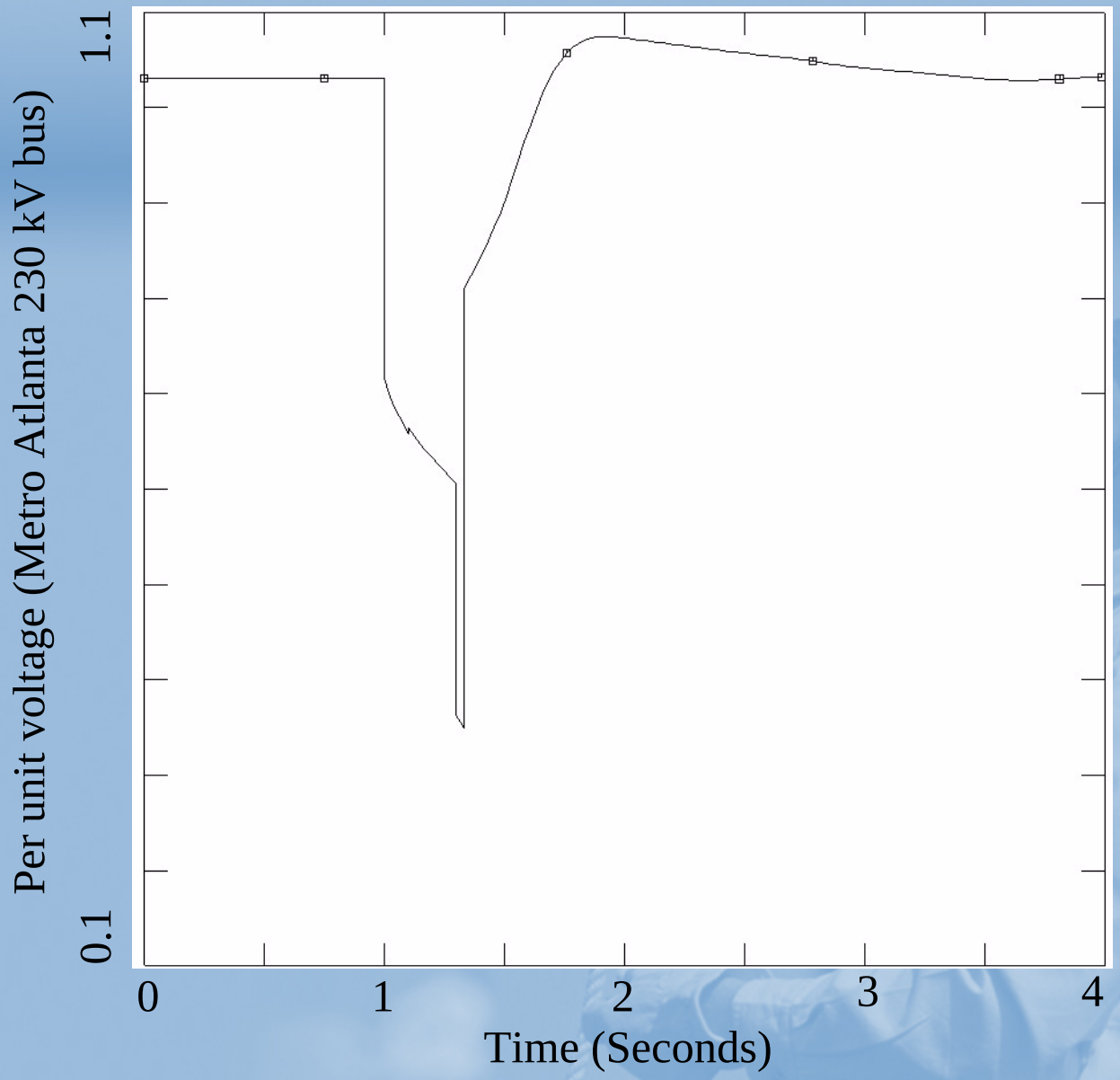

Motor MVA
Motor Power Factor
Power factor and load reactive power
Time (Seconds)
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0
2
4
6
8
10
12
14
16

Additional Model Validation Activities

- Since the 1999 Union City event, additional system events creating opportunities for further model validation have occurred
  - Compared to the 1999 event, these events were significantly less severe
  - Post-mortem simulations using the aggregate load model resulted in good, though not perfect, correlation



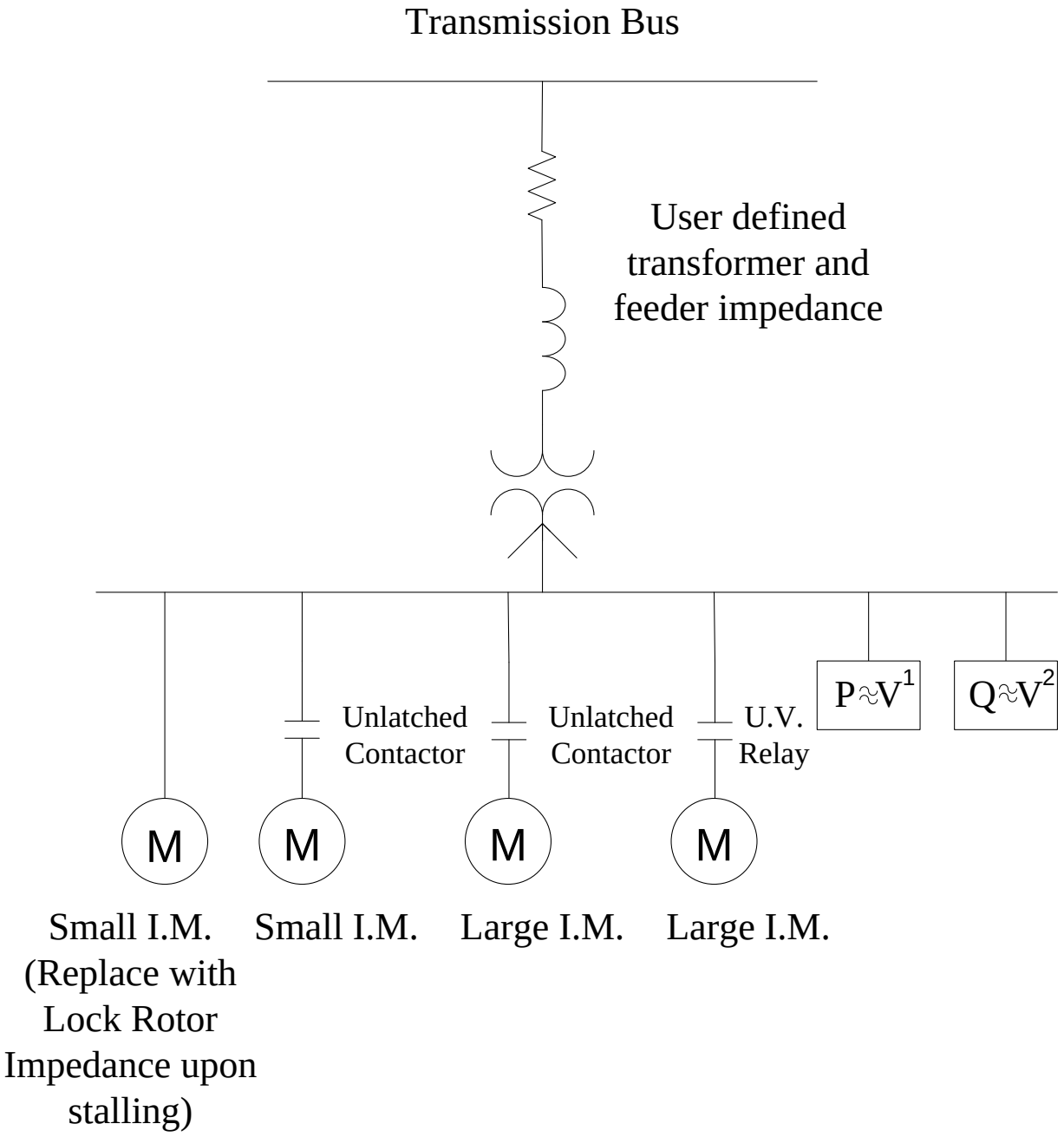
DFR recording of a less sever FIDVR event



Dynamic Simulations of a less severe FIDVR event

Possible Load Model Refinements

- Aggregate Load Model is being used in Planning and Operational assessments
  - High confidence that it results in appropriately conservative results
  - However, reality is that real-world aggregate load is more complex that currently modeled
  - Thus, a “user written” aggregate load model is under consideration which could include:
    - Residential loads
    - Commercial loads
    - Industrial loads


Transmission Bus
User defined transformer and feeder impedance
Unlatched Contactor
Unlatched Contactor
U.V. Relay
P≈V1
Q≈V2
M
M
M
M
Small I.M. (Replace with Lock Rotor Impedance upon stalling)
Small I.M.
Large I.M.
Large I.M.

Conclusions

- The aggregate load model currently in use by Southern Company Transmission was developed as a result of post mortem activities after the Union City 1999 event
- Induction Motor dynamics is the most critical component of the aggregate load model
- Southern Company Transmission is currently investigating a more detailed aggregate load model
  - The more detailed aggregate load model will be used only after detail analysis confirms that use of this model results in superior correlation with recorded system events.

DISCUSSION and QUESTIONS