EMTP-RV use at EPRI for Open Phase Analysis

EMPT-RV/Powersys Meeting
July 10, 2015

Introduction – EPRI Research

- EPRI has developed and is further developing application guides for EMTP-RV
  - (2011) Application Guide for Determining Maximum Switching Transient Overvoltages of Overhead Lines Rated 100 kV and Above Using Electromagnetic Transients Program (EMTP)
  - (2015) Application Guide for Determining Line T-Values used for Minimum Approach Distances Using Electromagnetic Transients Program (EMTP)
  - (2015) Application Guide for performing Open Phase Analysis Using Electromagnetic Transients Program (EMTP)

Introduction – EPRI Research

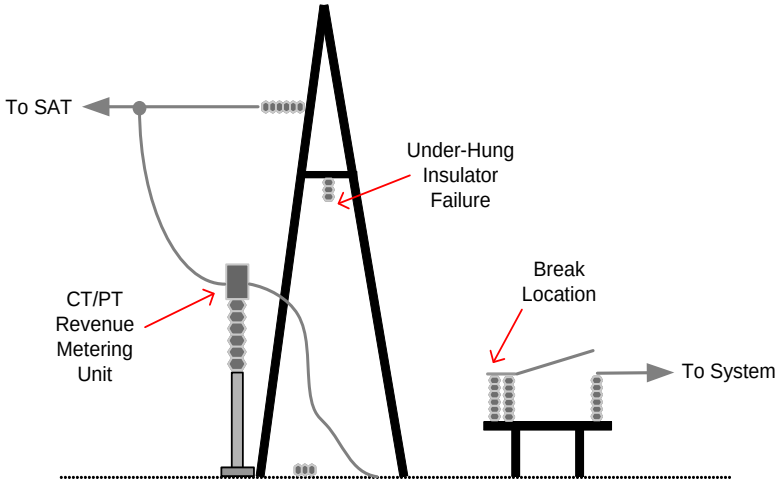
- Address many of the technical issues associated with detecting an open-phase condition of a station auxiliary transformer (SAT)
  - Studied several types of transformer types

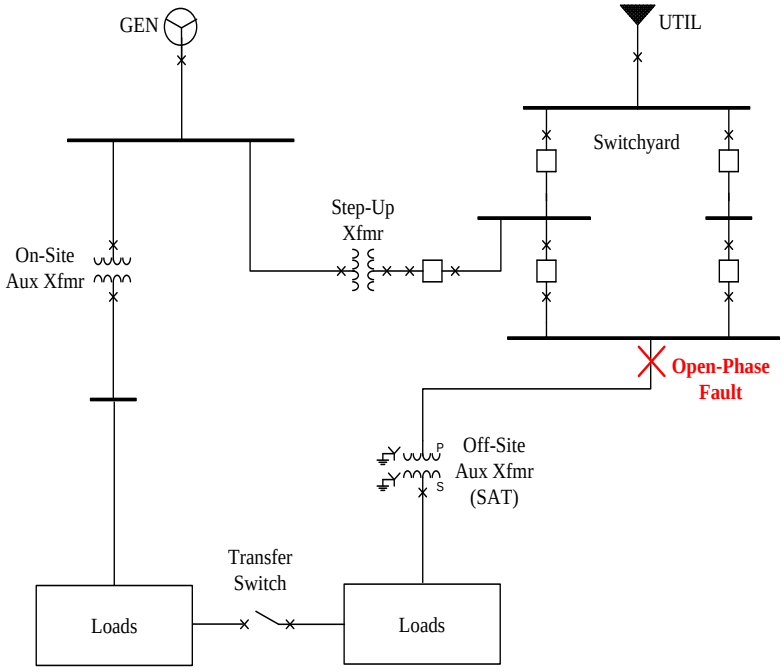
Released 4 publicly available documents on the open-phase issue since 2012 that used EMTP-RV.

Open Phase Modeling Inputs

- Transformer model
  - Knowledge of transformer type
    - Windings
    - Core Configuration
- Motor Modeling
  - Starting characteristics

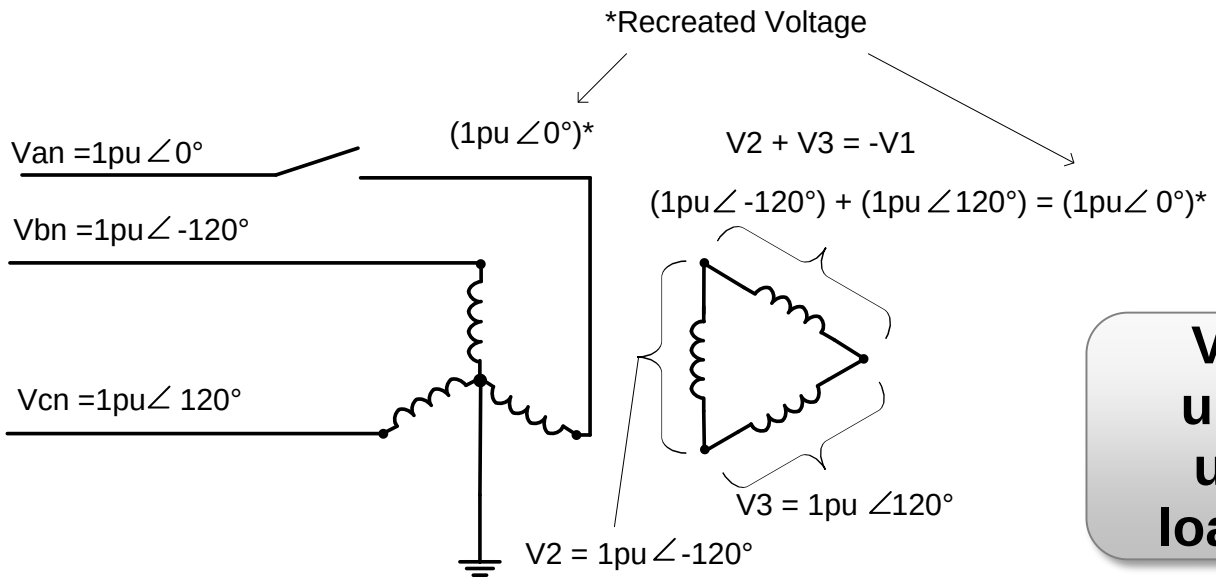
EMTP-RV results verified with alternative software.





Problem Description

- Transformers with wye-grounded connected primaries that have a zero-sequence impedance path i.e. secondary/tertiary delta or 3-legged core



Voltage remains undistorted even under moderate loading conditions

Problem Transformers (No Load)

Identified which transformer types exhibited this issue

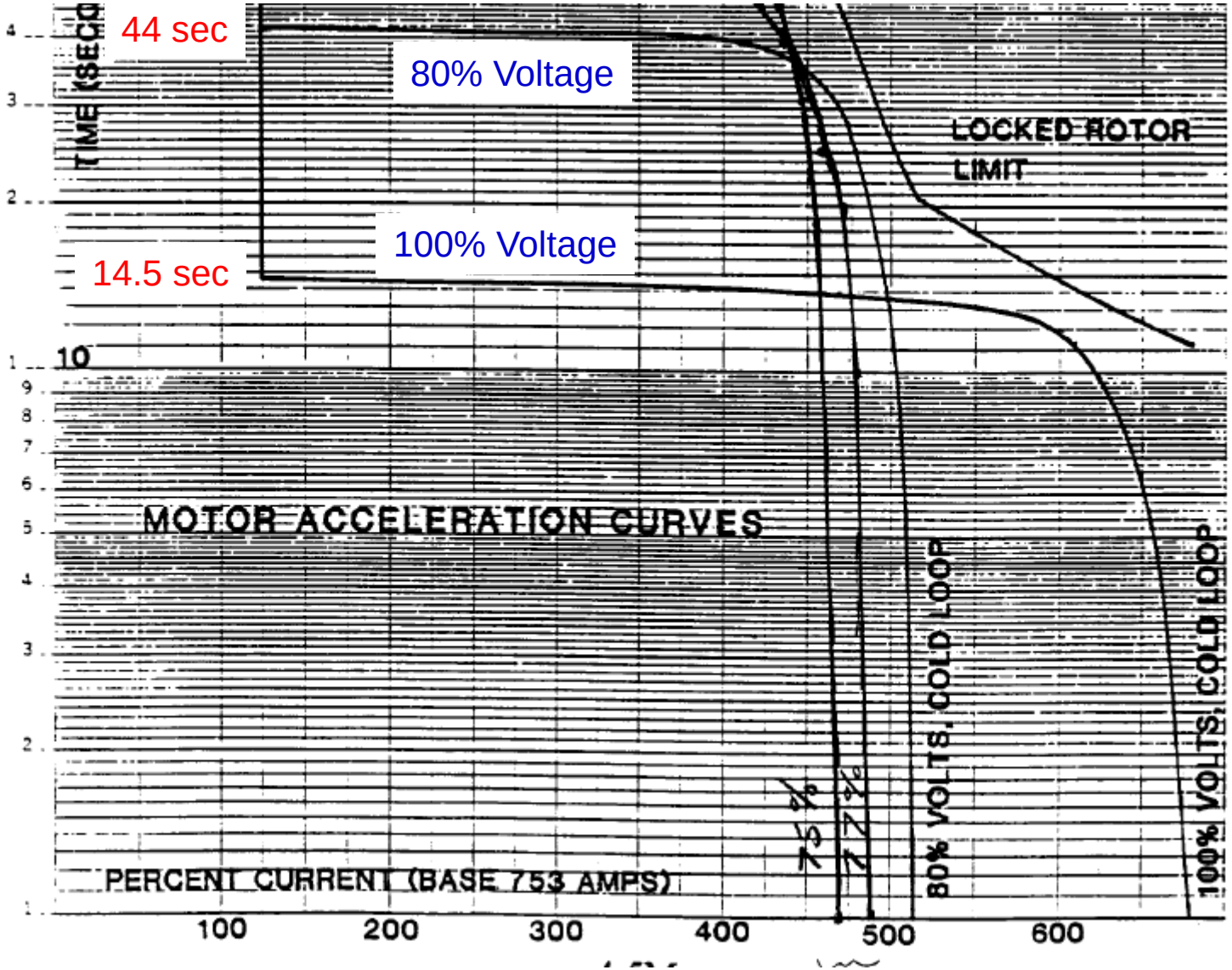
- Phase A opened on high side

	Primary Voltage (pu)			Secondary Voltage (pu)		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Wye-Wye (Shell Core)	**0**	1.0	1.0	**0**	1.0	1.0
Wye-Wye (3-Single Phase Cores)	**0**	1.0	1.0	**0**	1.0	1.0
Wye-Wye* (5-Legged Core)	**0.54**	1.0	1.0	**0.54**	1.0	1.0
Delta-Wye (3-Legged Core)	**0.5**	1.0	1.0	**0.5**	1.0	**0.5**
Wye-Delta (3-Legged Core)	1.0	1.0	1.0	1.0	1.0	1.0
Wye-Wye (3-Legged Core)	1.0	1.0	1.0	1.0	1.0	1.0
Wye-Delta-Wye (Shell Core with Buried Delta)	1.0	1.0	1.0	1.0	1.0	1.0

Motor Modeling Examples

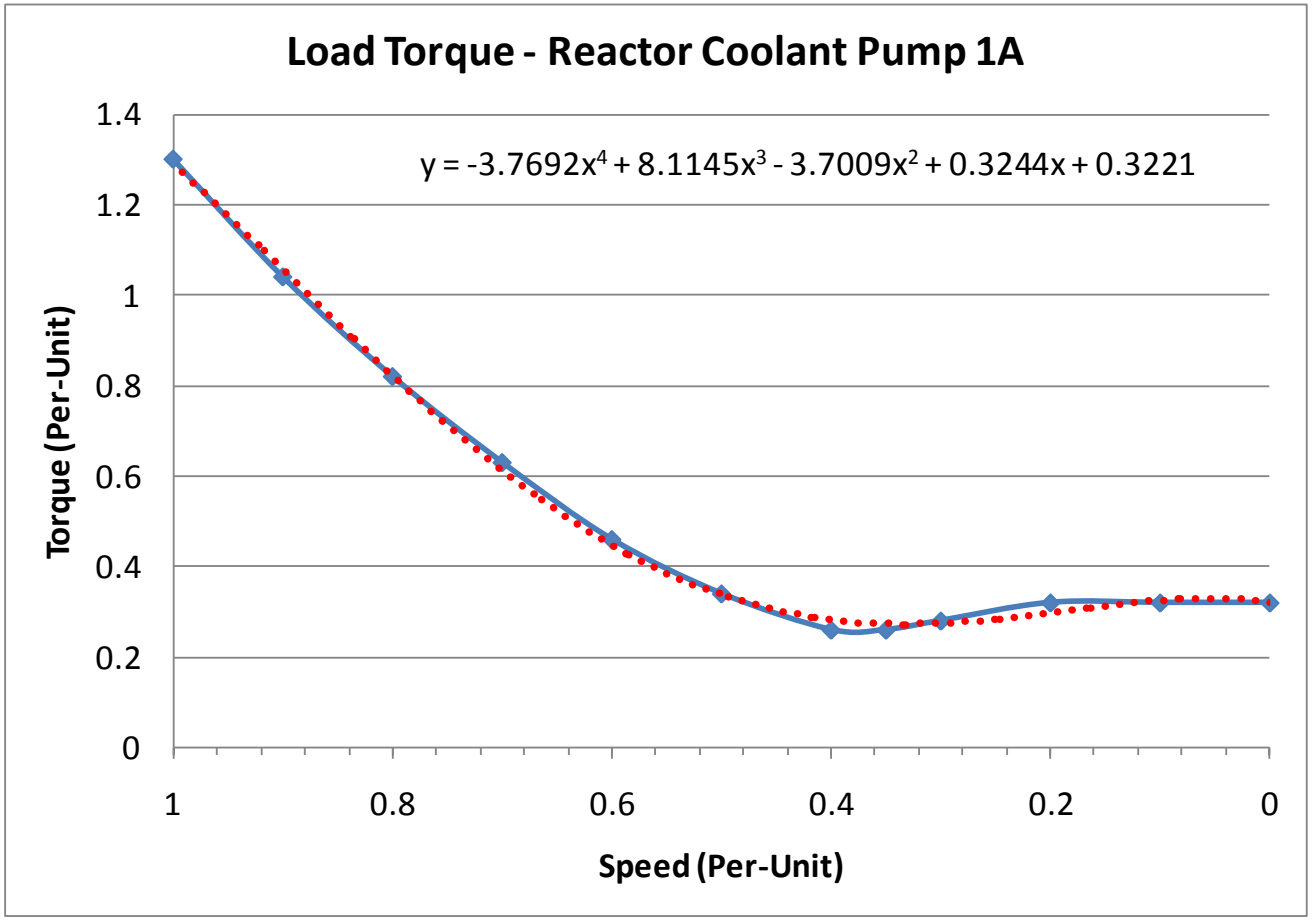
- Simulations were performed using EMTP-RV to determine if the 6000 HP Reactor Coolant Pump 1A motor could be started with an open phase on the high side of the station auxiliary transformer.
- Motor parameters were estimated using available nameplate data.
- Motor was started “across the line” with and without additional motors being connected to Bus 1A.

Calculated Acceleration Times



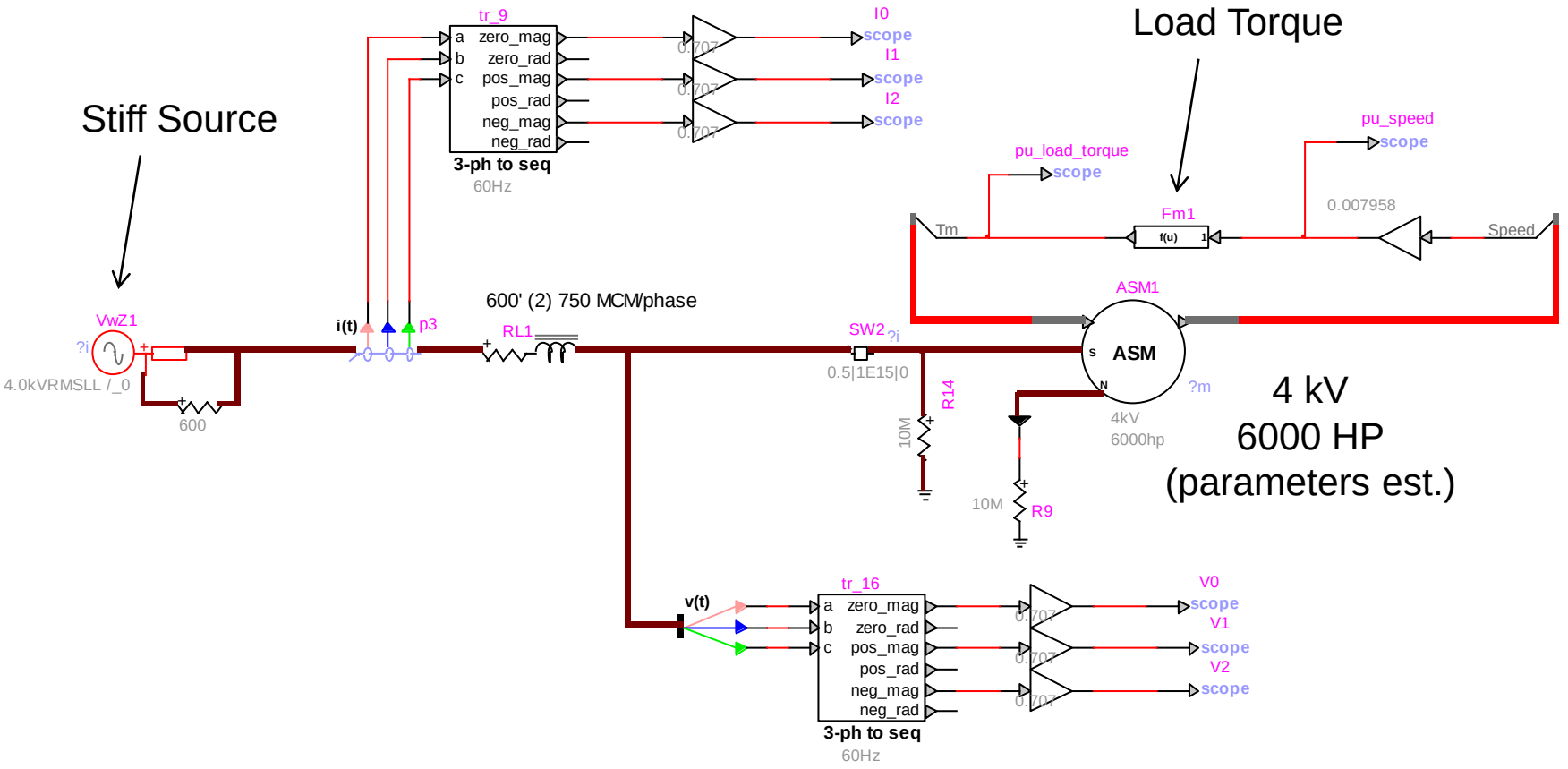
Load Model

- Pump Load Torque Curve

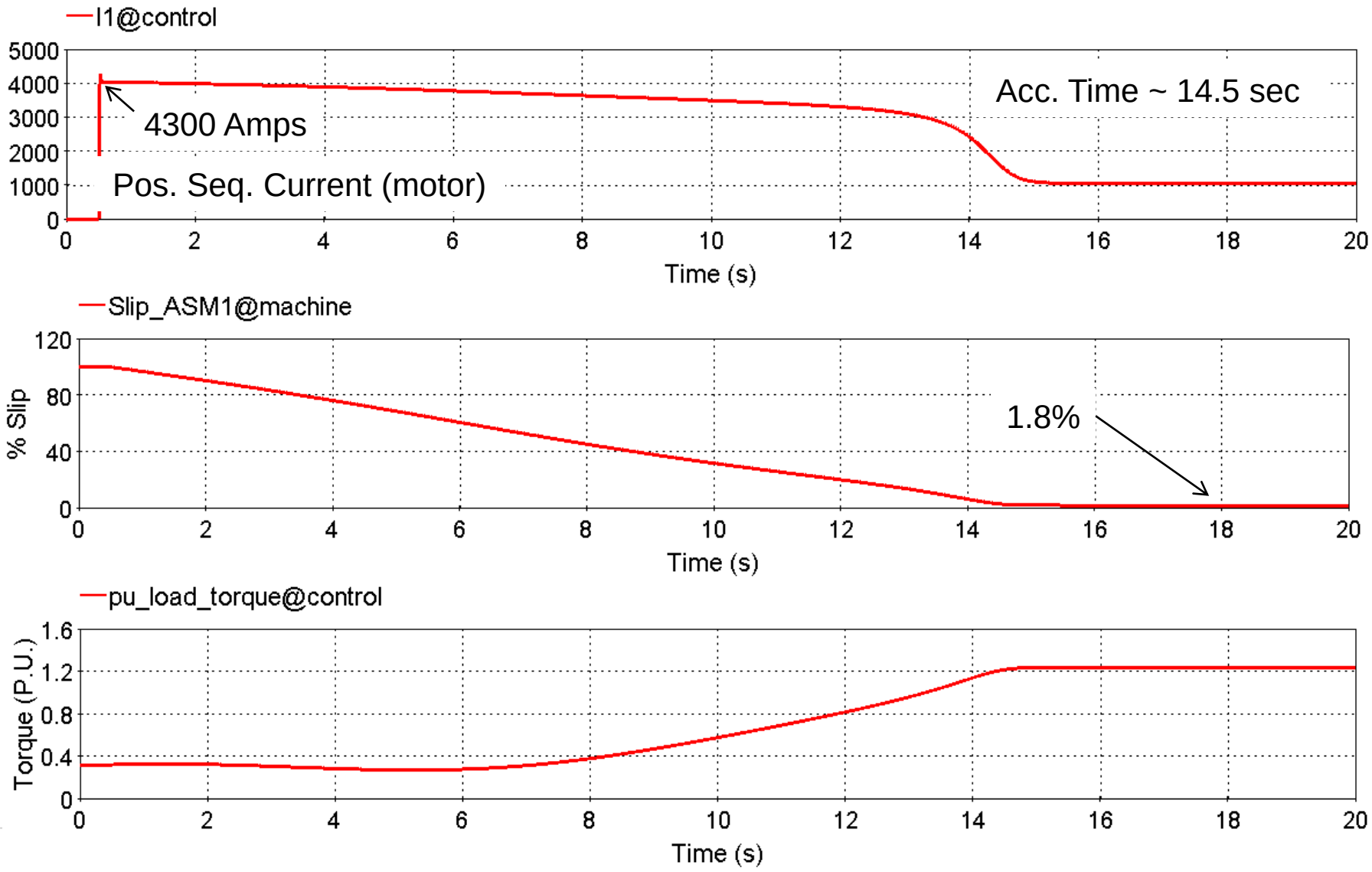


Model Validation

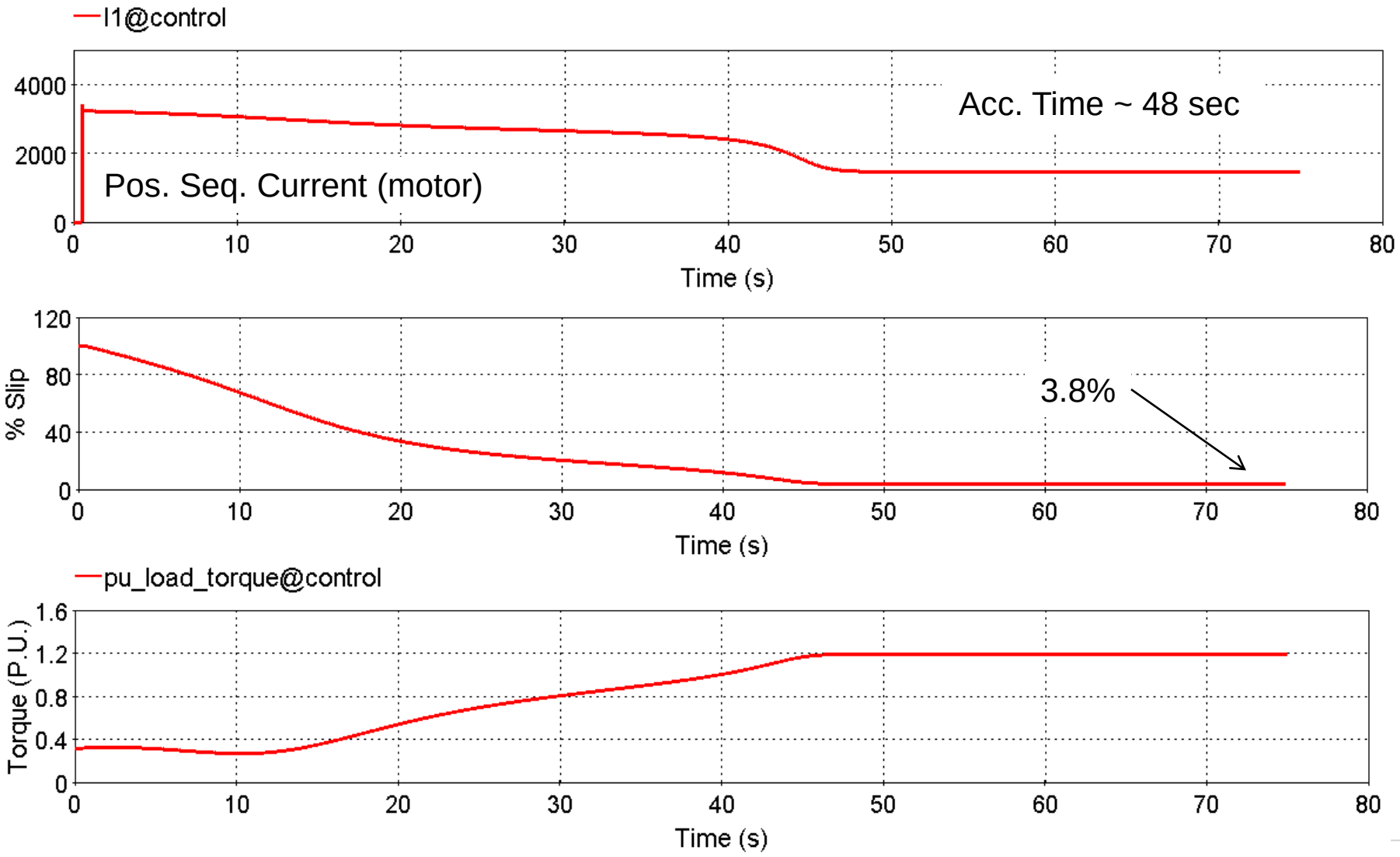
- EMTP-RV Model Used for Model Validation



Model Validation (Start at 100% Voltage - 4 kV)

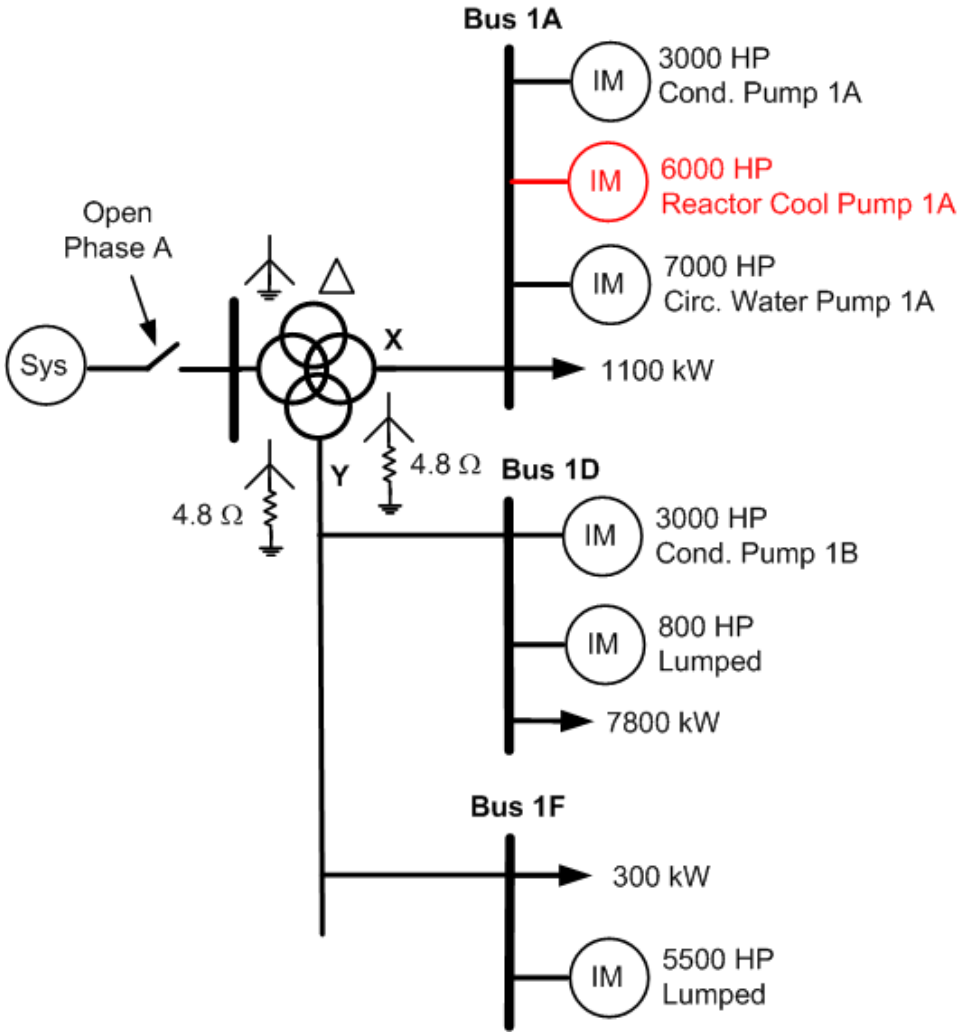


Model Validation (Start at 80% Voltage – 3.2 kV)

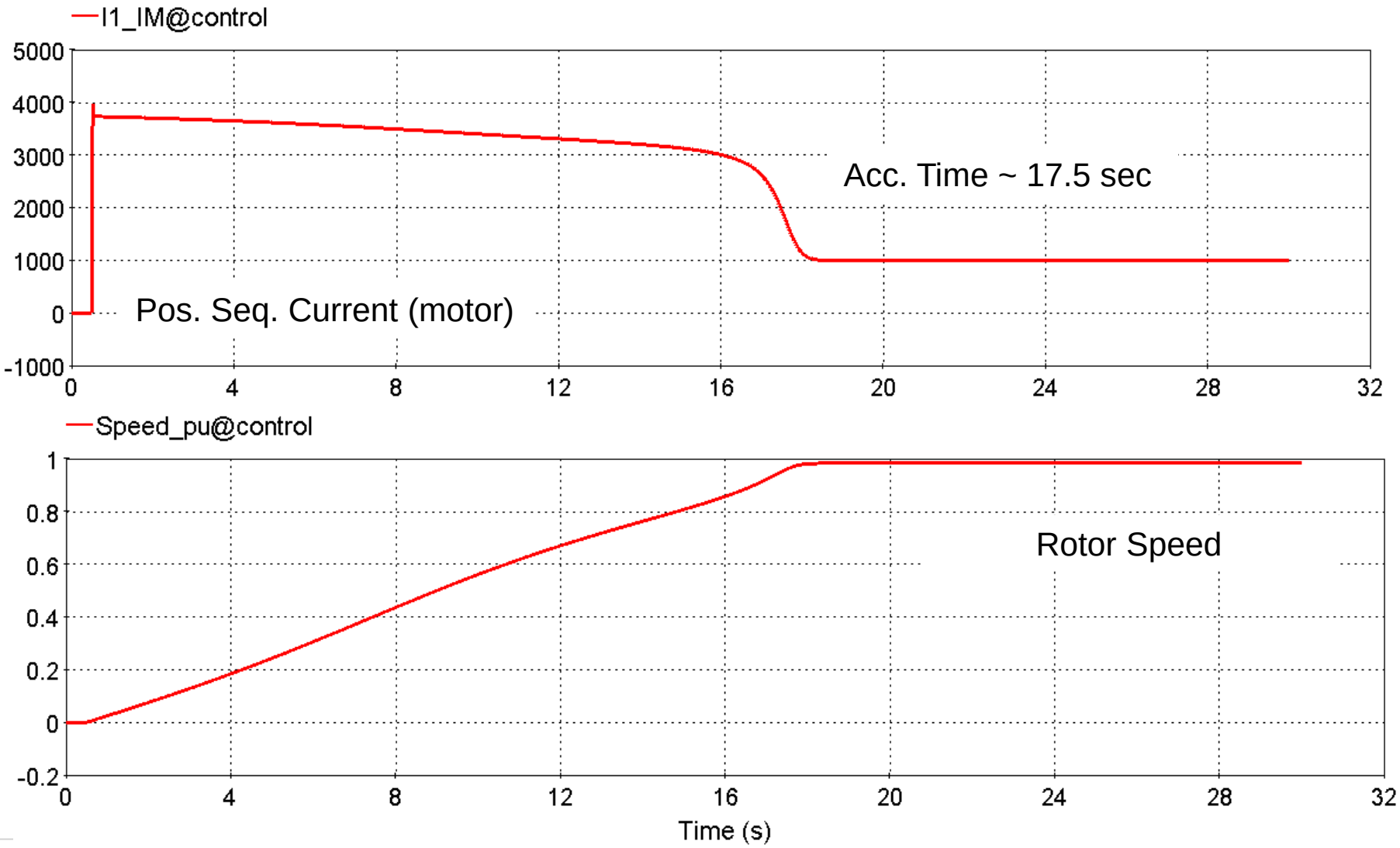


System Model

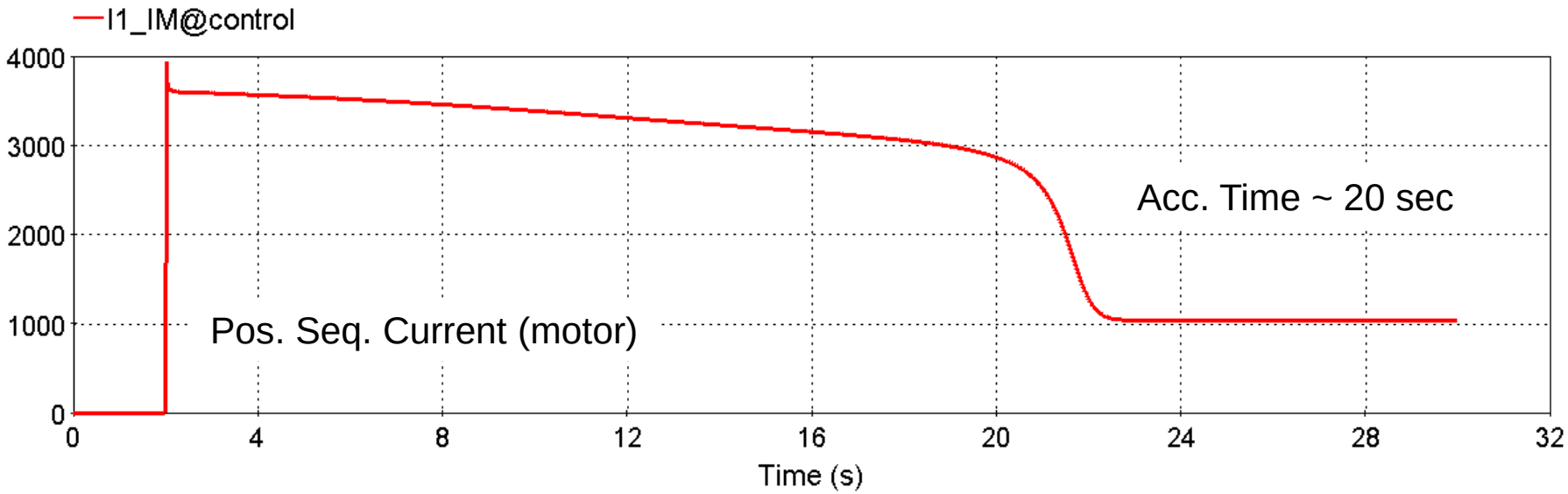
- Detailed time-domain model of system was constructed using EMTP-RV.
- Motor starting simulations were performed with and without open phase and with and without additional motors connected to Bus 1A.

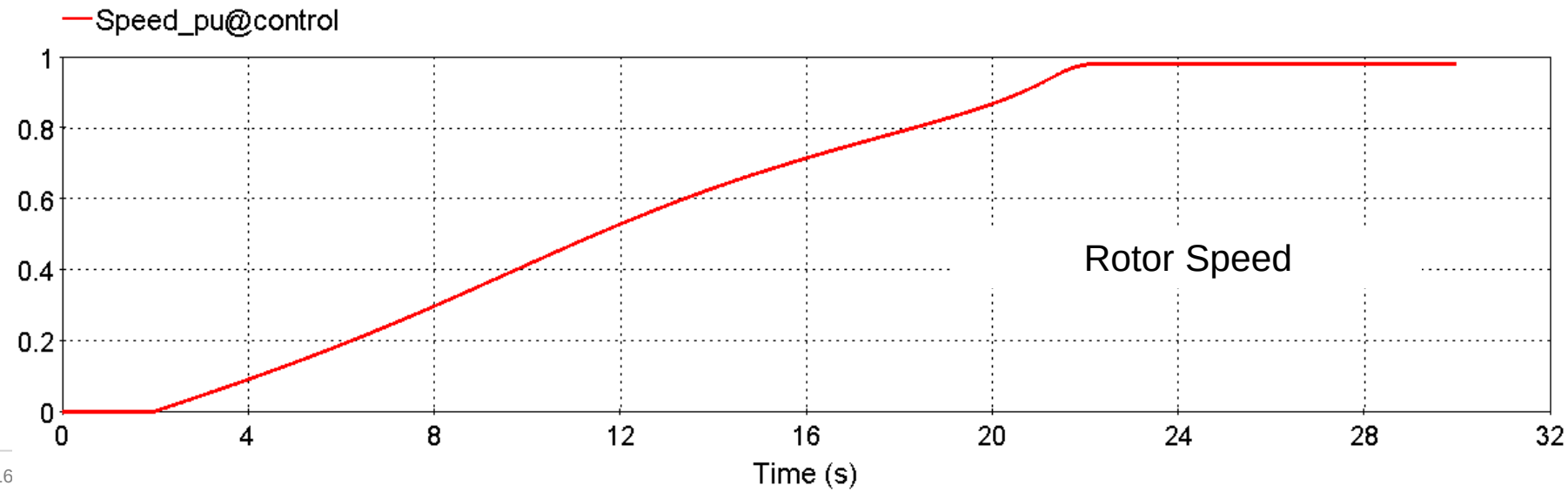


Motor Start (Normal Conditions – No Other Motors Connected to Bus 1A)

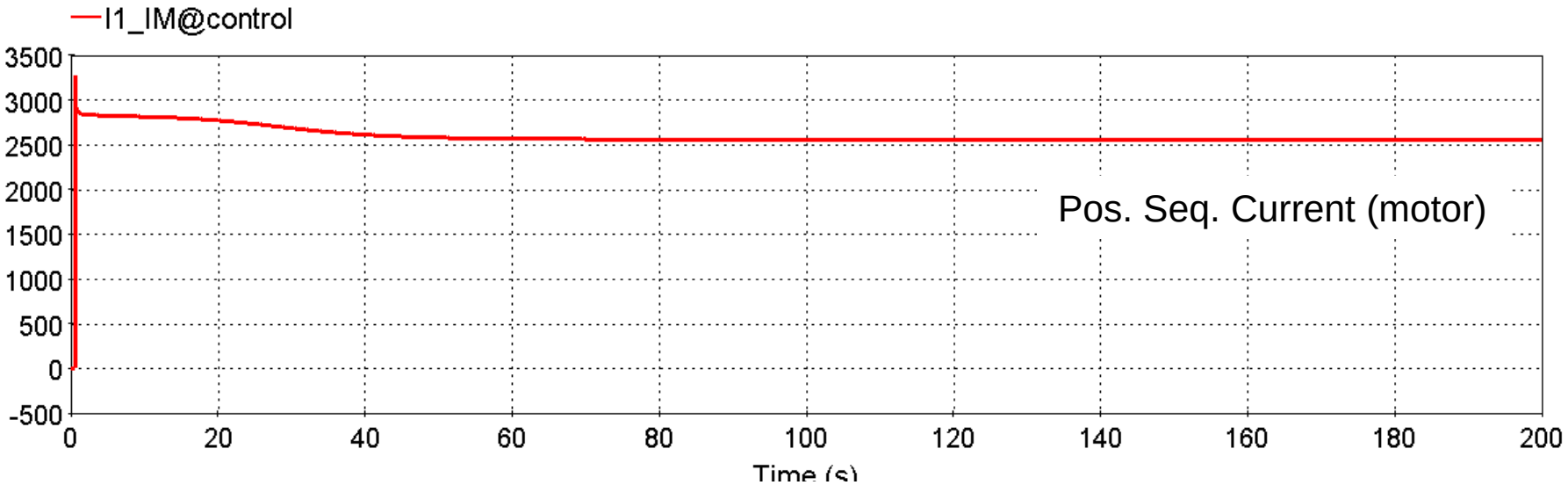


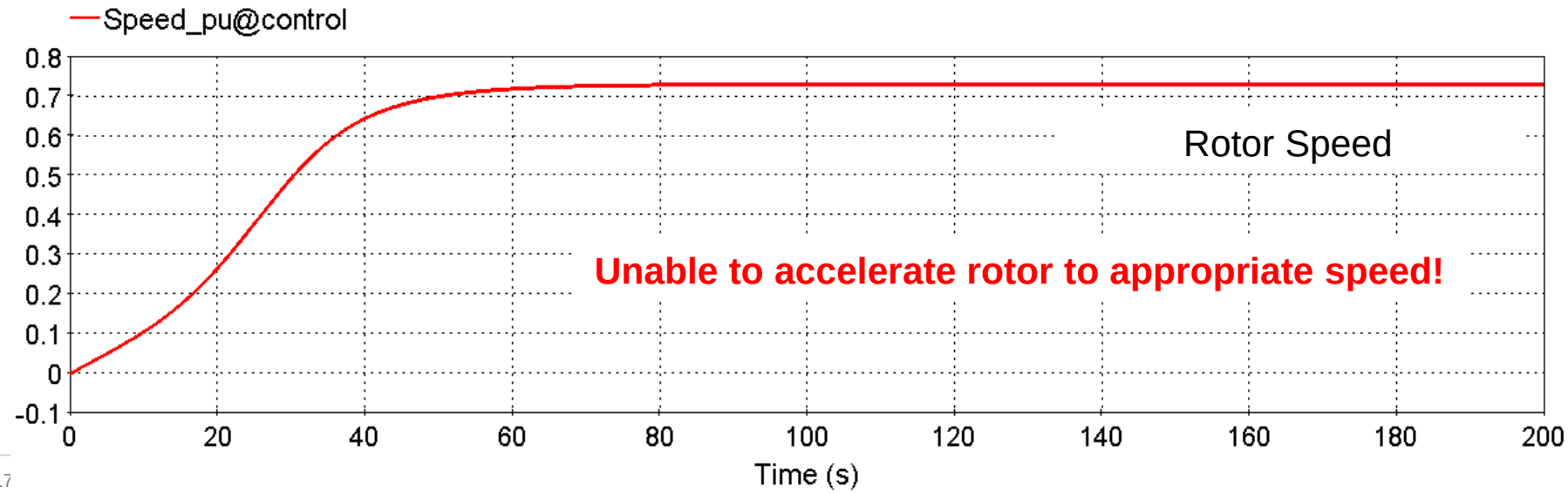
Motor Start (Normal Conditions – Motors Connected to Bus 1A)



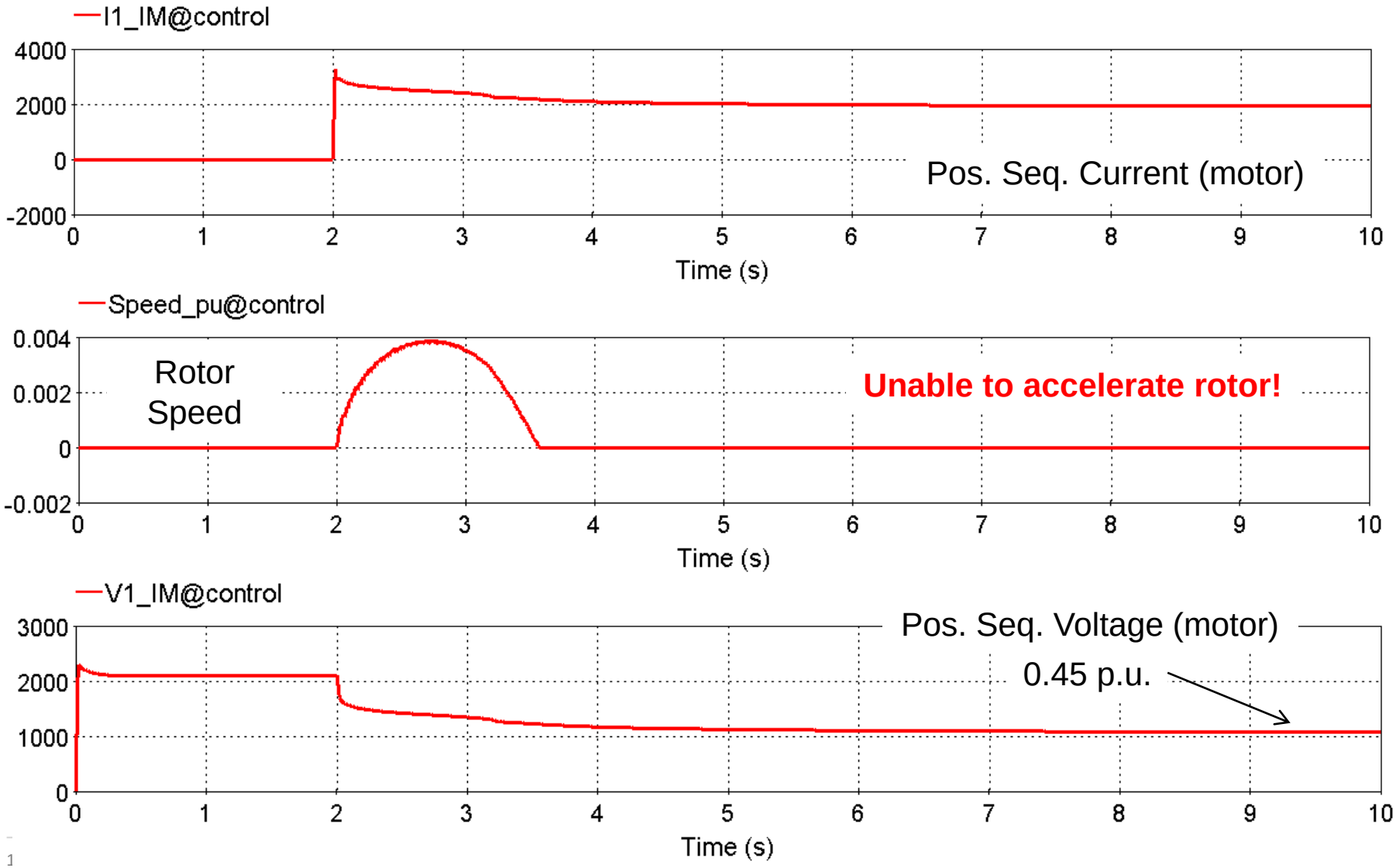


Motor Start (With Open Phase – No Other Motors Connected to Bus 1A)





Motor Start (With Open Phase –Motors Connected to Bus 1A)

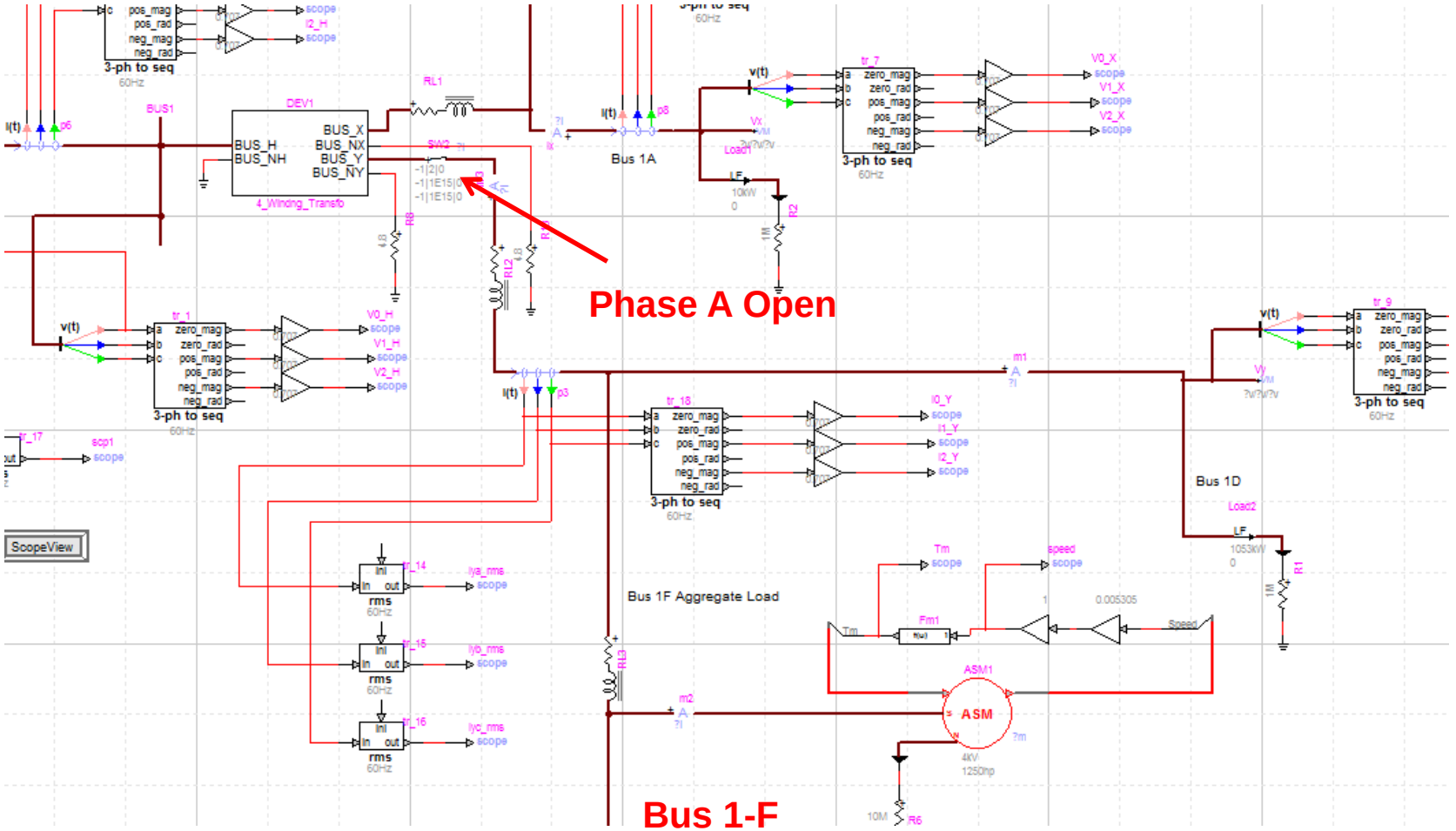


Conclusions

- The parameters of the EMTP-RV motor model were estimated using available nameplate data.
- The response of the model was compared to simulation results provided by the manufacturer. A reasonable comparison was obtained using the proposed model.
- Simulation results (with and without additional motor load) indicate that Reactor Coolant Pump 1A **can <u>not</u> be started** when an open phase condition occurs on the primary side of the station auxiliary transformer.
  - Additional motors connected to Bus 1A causes additional voltage drop at motor terminals resulting in reduced starting torque compared with the case where no motors are connected to Bus 1A.

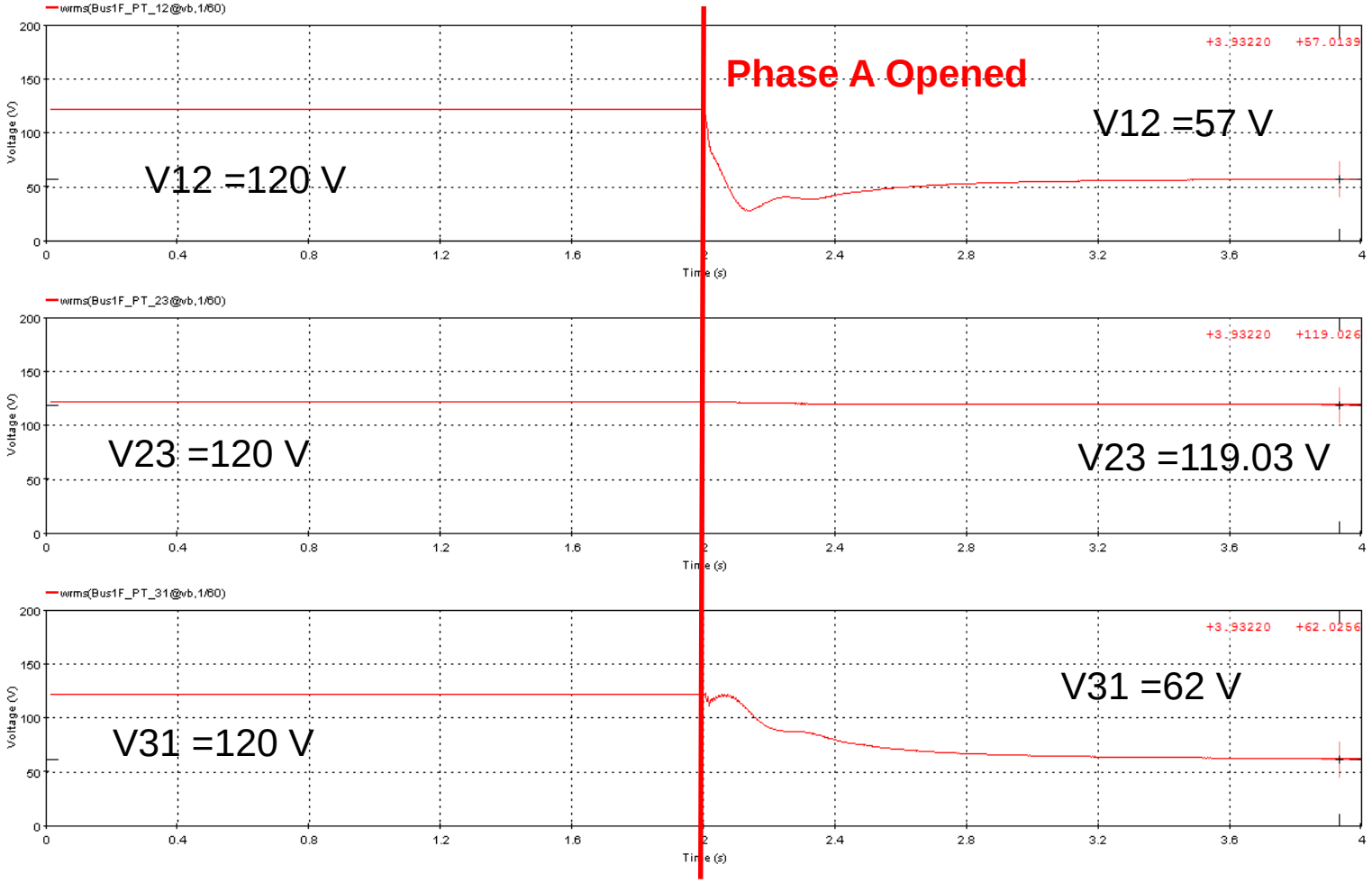
Fault Placement

- Open-Phase A on Secondary on Winding Y



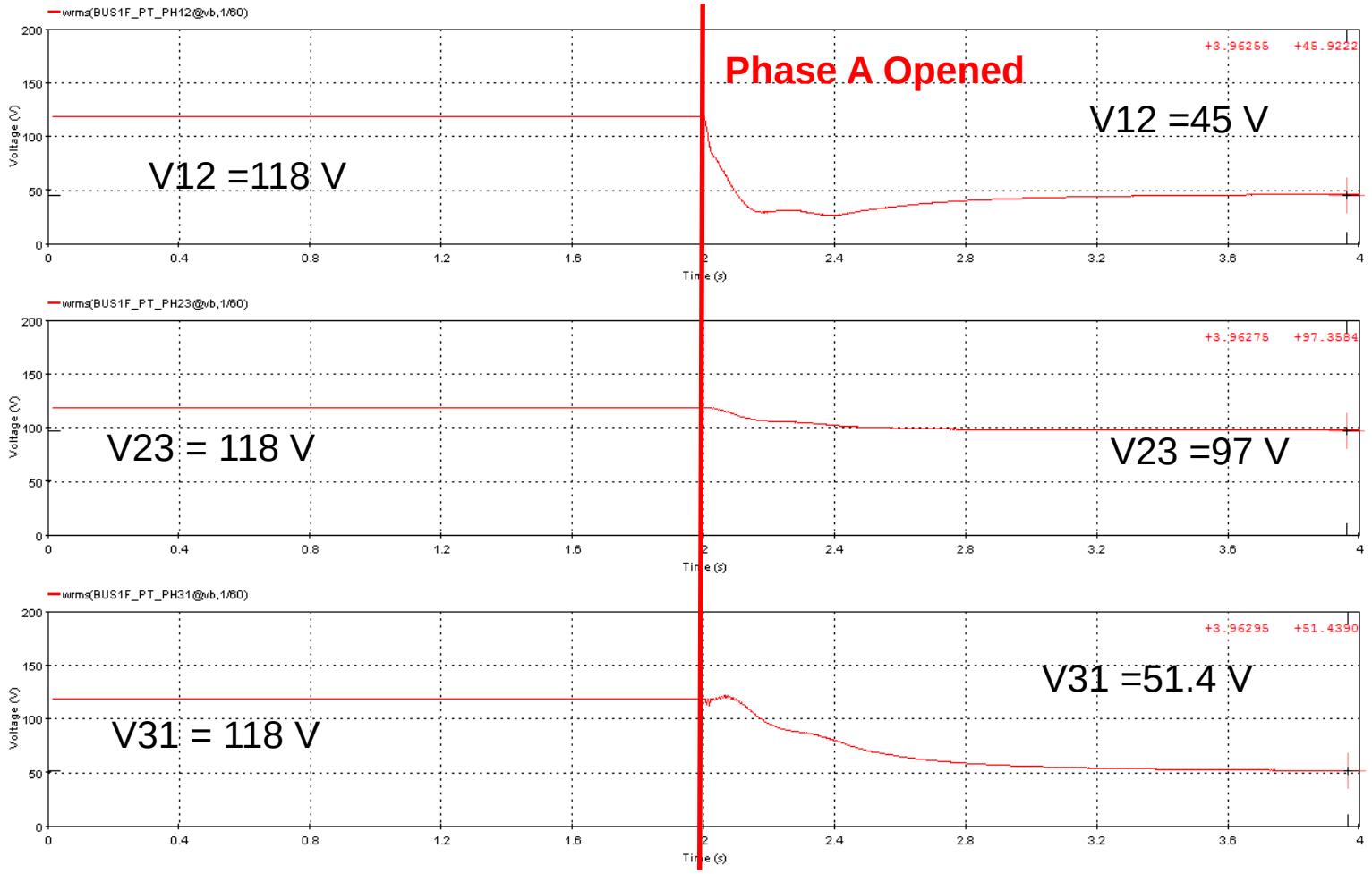
Light-Load Case – Bus 1-F

- Open-Phase A on Secondary on Winding Y



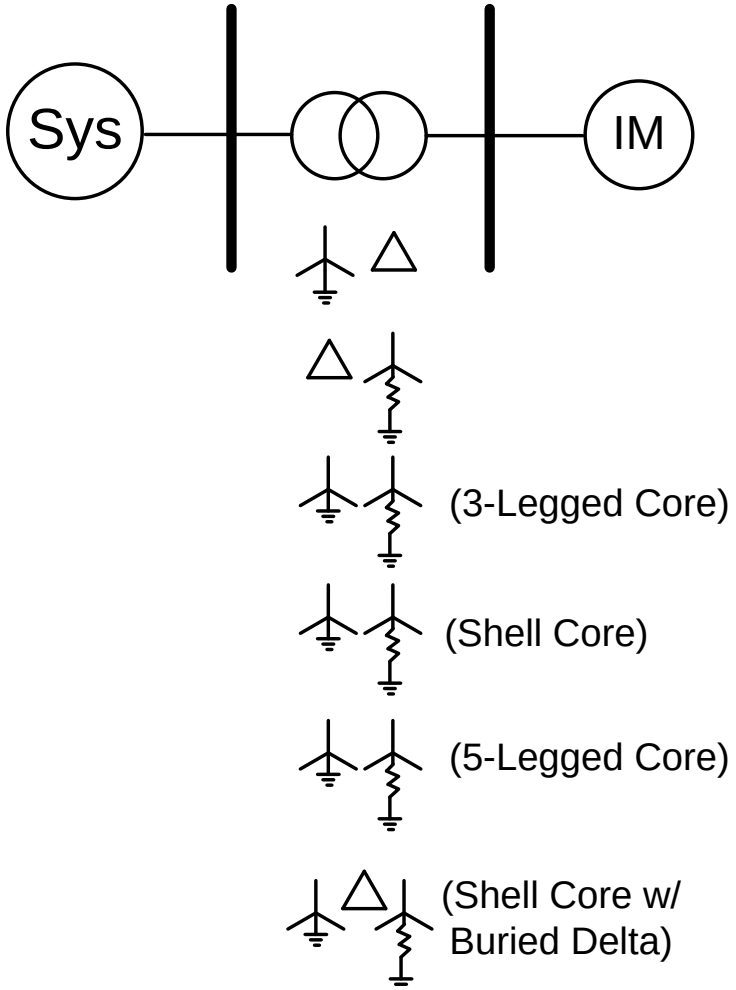
Heavy-Load Case – Bus 1-F

- Open-Phase A on Secondary on Winding Y



Double Open-Phase Analysis

- Transformer Core/Winding Configurations
  - The goal of this research was to understand if detecting a double open-phase condition of a station auxiliary transformer would be affected by its connection and/or core configuration.
  - For use in the analysis and determining, in general, the response of the system(s) during a double open-phase event.



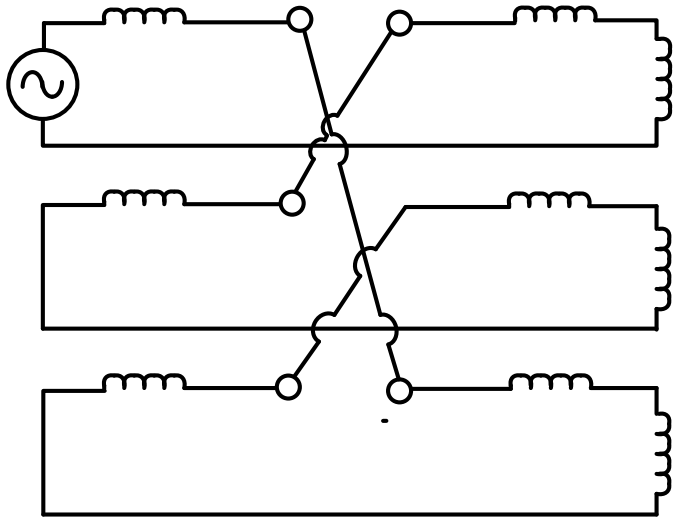
No-Load Conditions

- No-load conditions, both primary and secondary exhibit low voltage conditions.
- Unable to start 3-phase induction motors.

	Primary Line-Ground Voltage (pu)			Secondary Line-Ground Voltage (pu)		
Wye-Wye (Shell Core)	0	0	1	0	0	1
Wye-Wye (5-Legged Core)	0	0.44	1	0	0.44	1
Delta-Wye (3-Single Phase Cores)	1	1	1	0	0	0
Wye-Wye (3-Legged Core)	0.5	0.5	0.99	0.86	0	0.86
Wye-Delta (3-Single Phase Cores)	0.5	0.5	0.99	0.86	0	0.86
Wye-Wye (Shell Core with Buried Delta)	0.5	0.5	0.99	0.86	0	0.86

Light Load (<10% Transformer Rating)

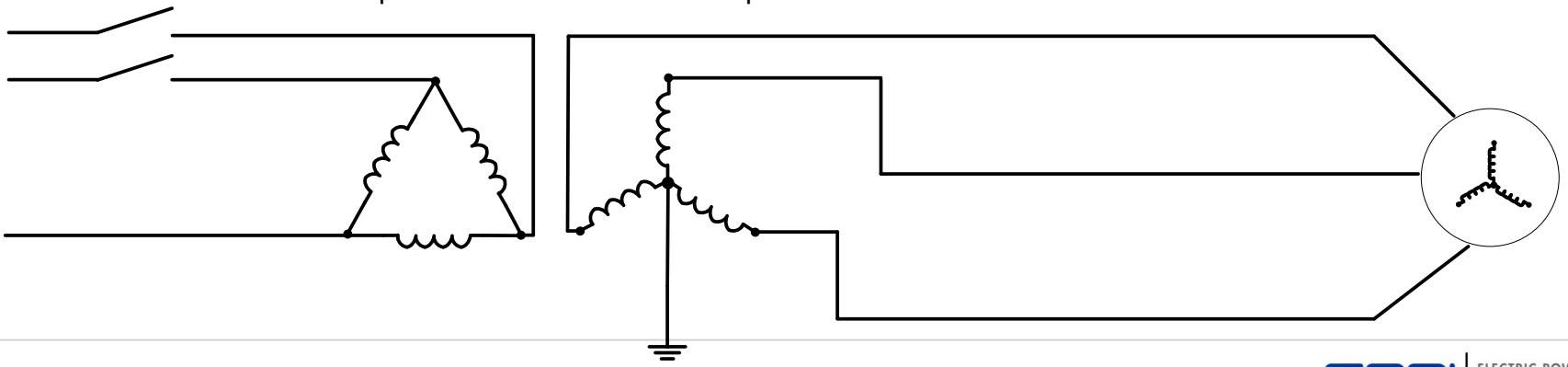
- Delta – Grounded Wye (230kV:4.16kV 25 MVA)
- Motors stop spinning



	V_1	V_0	V_2
Primary (H)	0 pu	**0.99 pu**	0 pu
Secondary (X)	0 pu	0 pu	0 pu

Van =1pu ∠0°
Vbn =1pu ∠0°
Vcn =1pu ∠0°

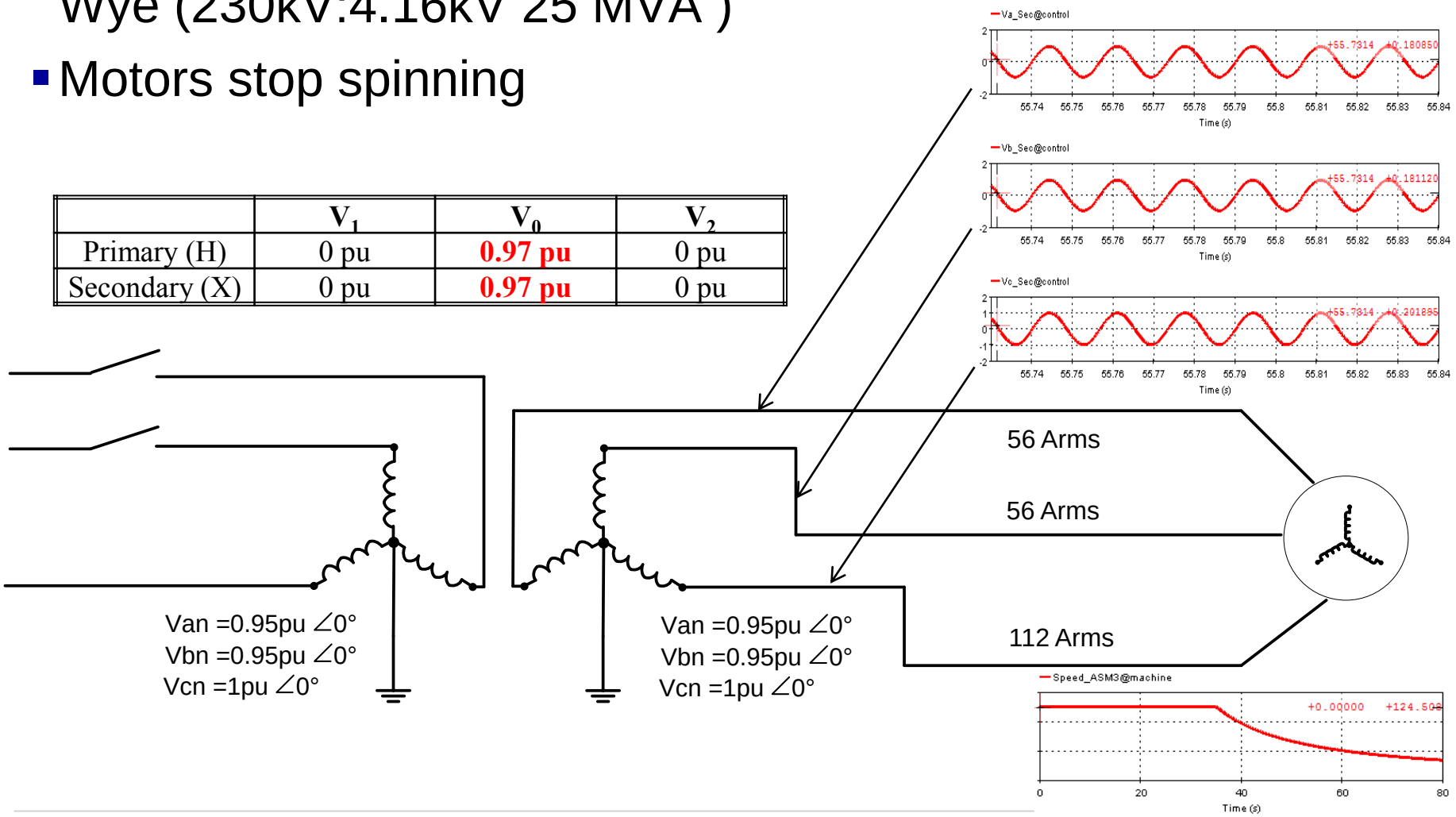
Van =0pu ∠0°
Vbn =0pu ∠0°
Vcn =0pu ∠0°



Light Load (<10% Transformer Rating)

- Shell Core, Grounded Wye – Grounded Wye (230kV:4.16kV 25 MVA)
- Motors stop spinning

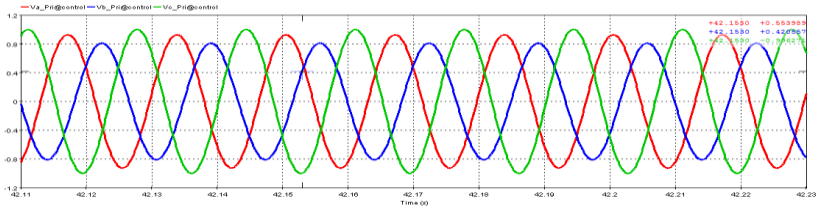
	V_1	V_0	V_2
Primary (H)	0 pu	**0.97 pu**	0 pu
Secondary (X)	0 pu	**0.97 pu**	0 pu

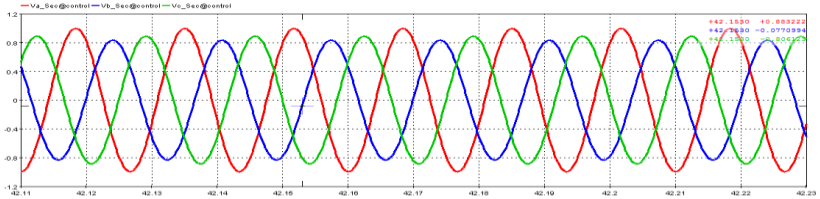


Light Load (<10% Transformer Rating)

- 3-Single Phase Cores, Grounded Wye – Delta (230kV:4.16kV 25 MVA)
- Motors keeps spinning

Primary LG Voltage (After Open)

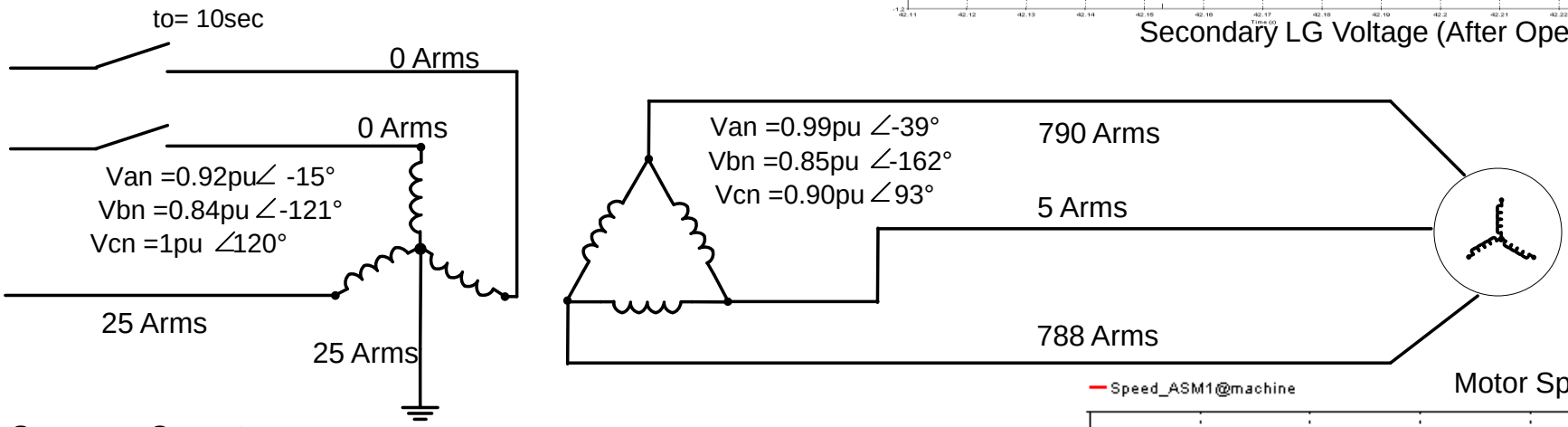




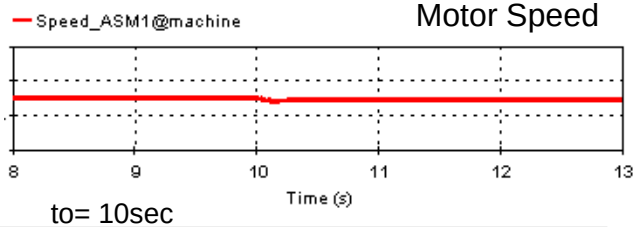
Secondary LG Voltage (After Open)

Sequence Voltages

	V_1	V_0	V_2
Primary (H)	0.91 pu	0.01 pu	0.09 pu
Secondary (X)	0.91 pu	0 pu	0.08 pu



Motor Speed



to= 10sec

Sequence Currents

	I_1 (A)	I_0 (A)	I_2 (A)	$\%I_0/I_1$	$\%I_2/I_1$
Primary (H)	8.3	8.3	8.3	100	100
Secondary (X)	453	0	457	0	101

General Conclusions

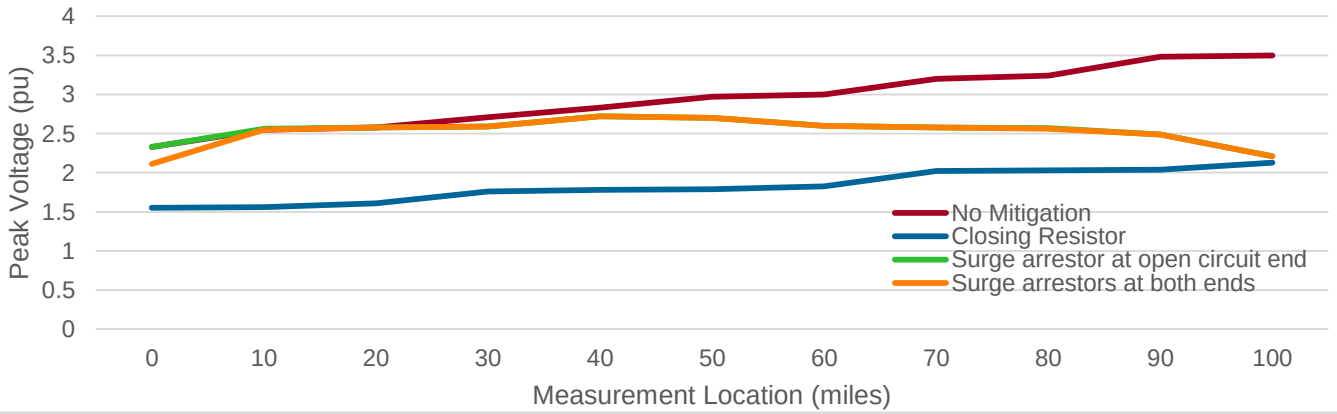
- No-load conditions result in low voltage conditions
- Transformers that exhibit the issues with a double open-phase are the same transformers that exhibit the issues with a single open-phase.
  - Voltage distortion becomes greater with larger loads.
- Conventional voltage relaying can be used for other transformer configurations

Other Work Conducted at EPRI

- Performed switching studies in response to OSHA's mandate on maximum switching transient values (T-levels)
- Scope
  - Identify critical parameters that drive voltage magnitudes
  - Conduct sensitivity analysis across critical parameters
  - Develop technical basis for categorizing lines by T-values

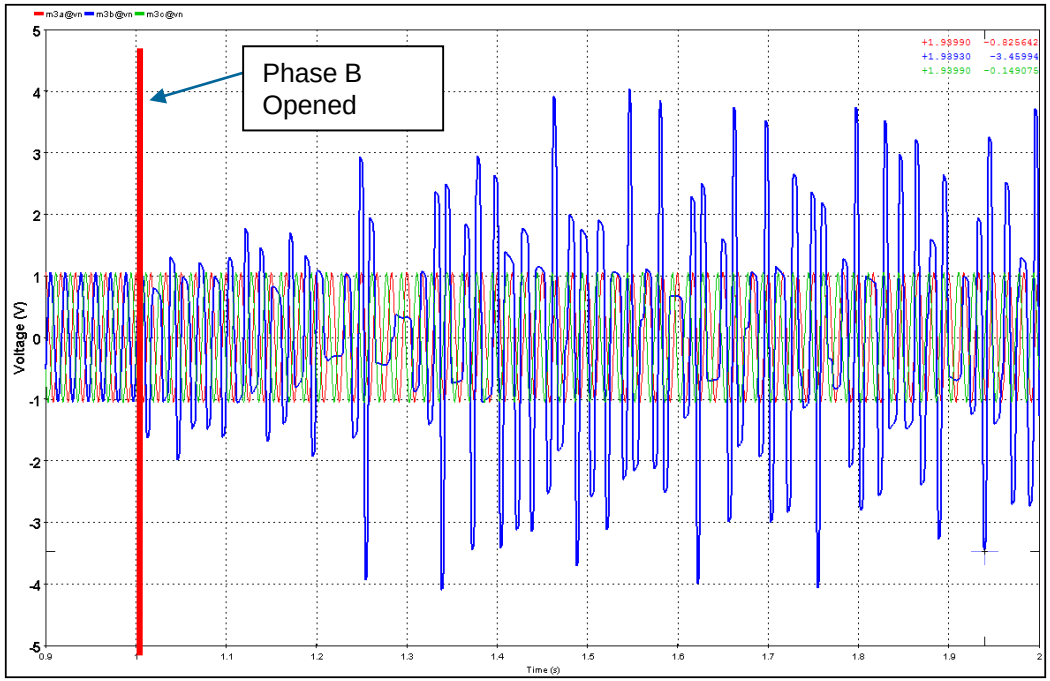
Scripted in EMTP-RV multiple variable perturbations

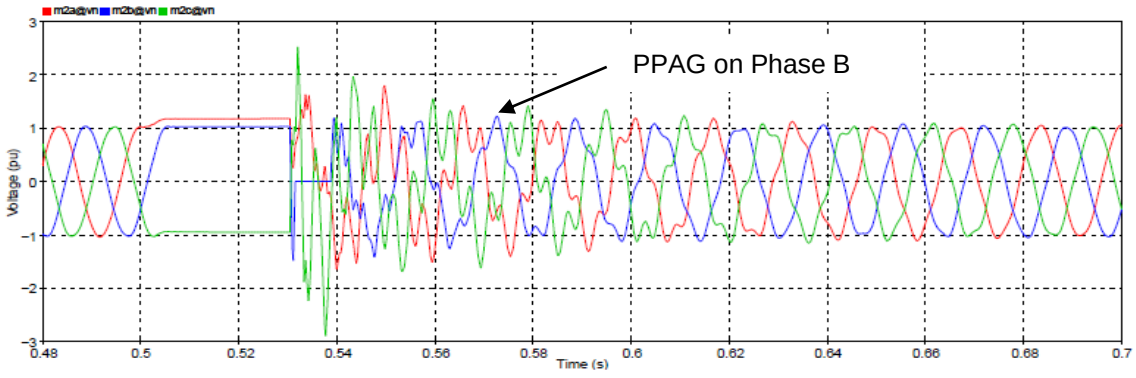
>150k simulations run.



Other Work Conducted at EPRI

- Switching studies
- Ferroresonance
- Lightning / Insulation Coordination
- Control Circuits
- System Imbalance
- Motor Starting
- Electrical cars
- Distributed Generation
- Etc.





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