NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Industry Webinar

Dynamic Load Modeling

NERC Load Modeling Task Force (LMTF)
December 2016

RELIABILITY | ACCOUNTABILITY




Introduction

- Goals:
  - Increase industry expertise and focus on dynamic load models and modeling practices
  - Share latest understanding and advancements in dynamic load modeling
  - Update industry on efforts underway in the NERC Load Modeling Task Force (LMTF)
- Webinar Topics
  - Fundamentals of end-use loads
  - Composite load model
  - Benchmarking and implementation
  - Load composition data
  - Distributed energy resource modeling
  - Related LMTF activities

NERC LMTF

- Kickoff January 2016
- LMTF webpage
- Key Focus Areas
  - Industry-wide engagement and participation – utilities, subject matter experts, software vendors, regional load modeling groups, etc.
  - Consolidate and share load modeling practices across industry
  - Support industry-wide advancement of dynamic load modeling
  - Develop guidelines, technical references, industry webinars, etc.
  - Help ensure robust software implementation
  - Share lessons learned and study approaches
- Chair: Dmitry Kosterev, BPA

Speakers

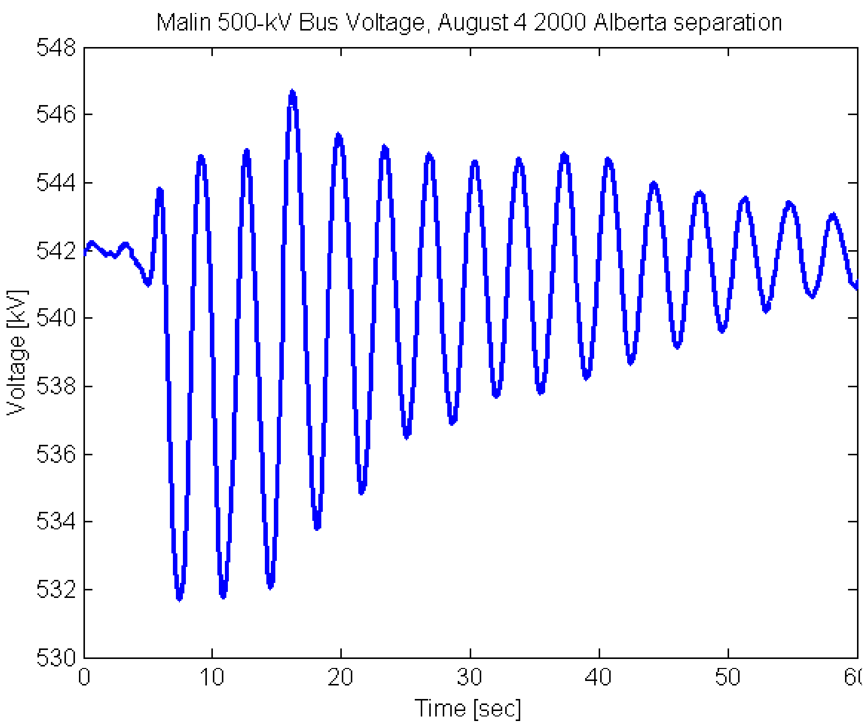
- Ryan Quint – *NERC (NERC LMTF Coordinator)*
- Dmitry Kosterev – *BPA (NERC LMTF Chair)*
- Hamody Hindi – *BPA (WECC LMTF Chair)*
- Bernie Lesieutre – *Univ. Wisconsin*
- Jamie Weber – *PowerWorld*
- John Undrill – *Consultant*

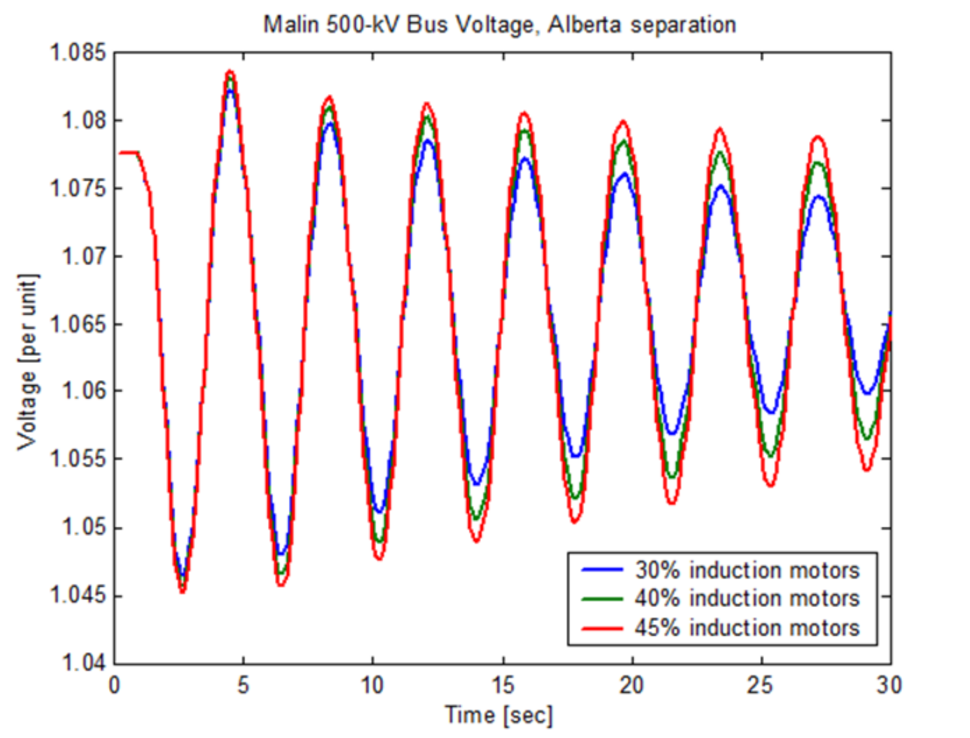
History & Background

Why is this important?
How did we get to where we are today?

Why Dynamic Load Modeling?

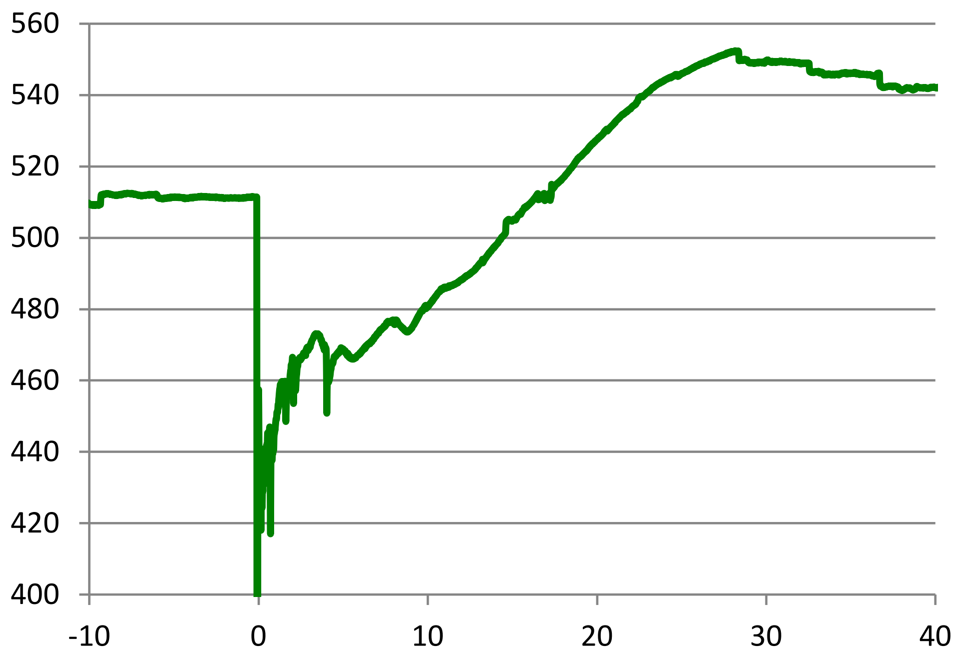
- Validation of power-voltage oscillations
  - WECC: July 2 and August 10 1996, August 4 2000





Why Dynamic Load Modeling?

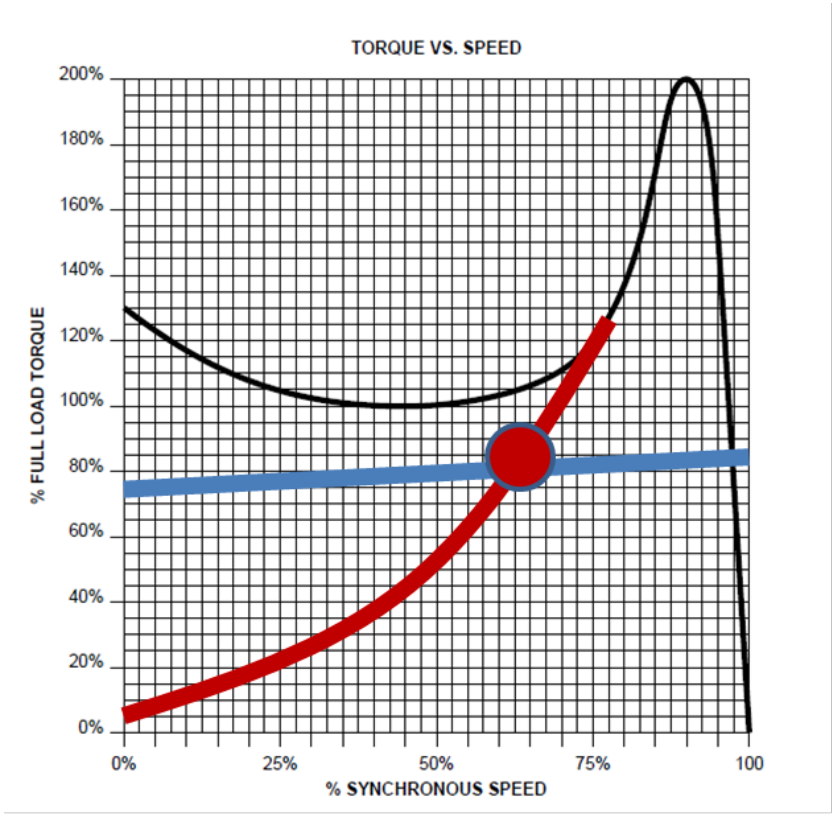
- Fault-Induced Delayed Voltage Recovery (FIDVR)
  - Observed as early as 1980s in So. California, Florida, Georgia, mid-West
  - Related to stalling of residential air-conditioners
- Distributed energy resources
  - Emerging need in early 2010s

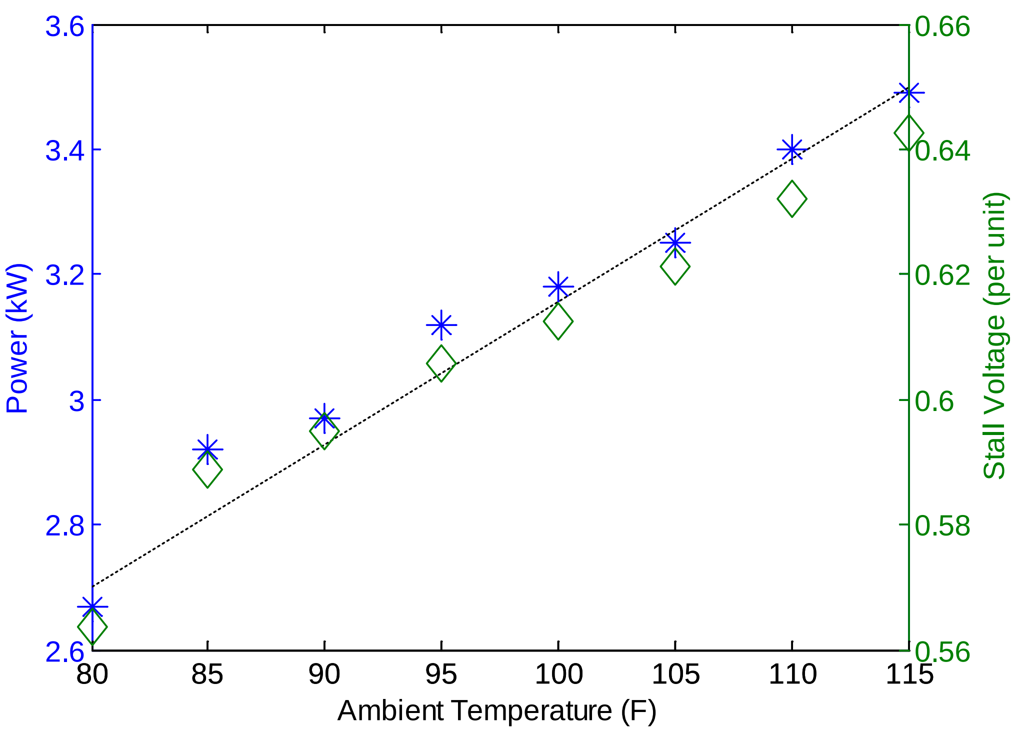


Air Conditioner Testing Round 1

- SCE, EPRI, and BPA tested single-phase residential A/C units
  - Voltage sags, ramps, oscillations, frequency excursions
- Stall for sudden ΔV to 50-60% of nominal in less than 3 cycles
- Once stalled, they remain stalled
  - Cannot overcome load torque - coolant pressure must equalize
- Reactive power up to ~ 7x rated
- Thermal protection trips in 2-30 seconds

Air Conditioner Testing Round 1





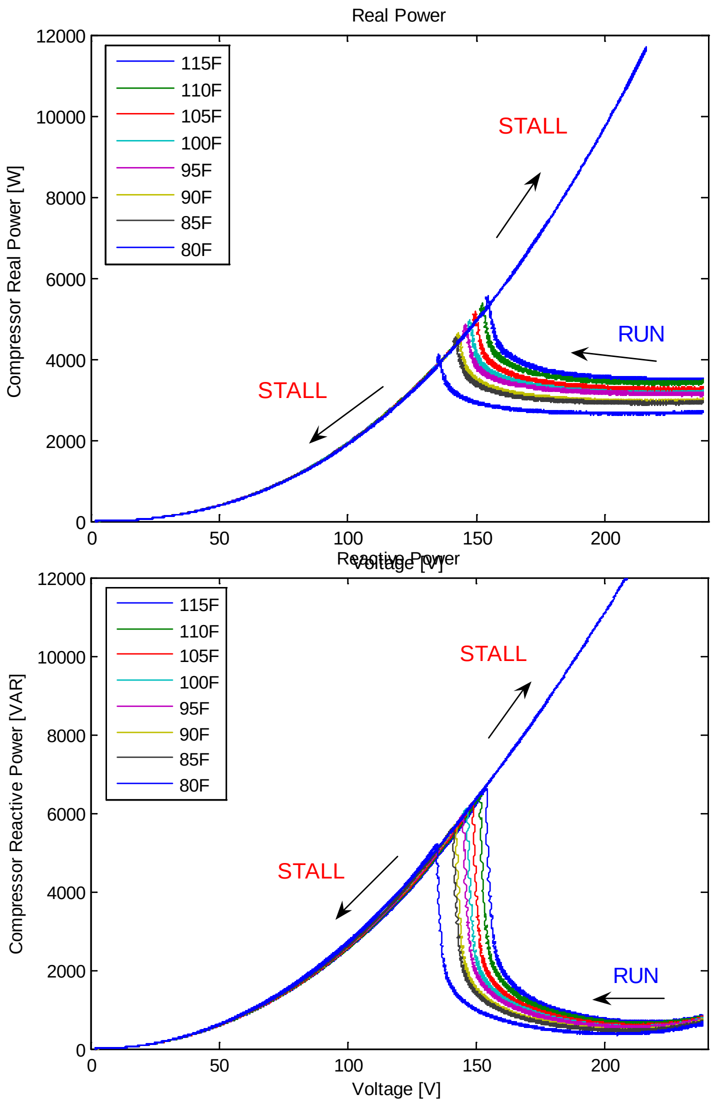
Three phase motor elec. torque

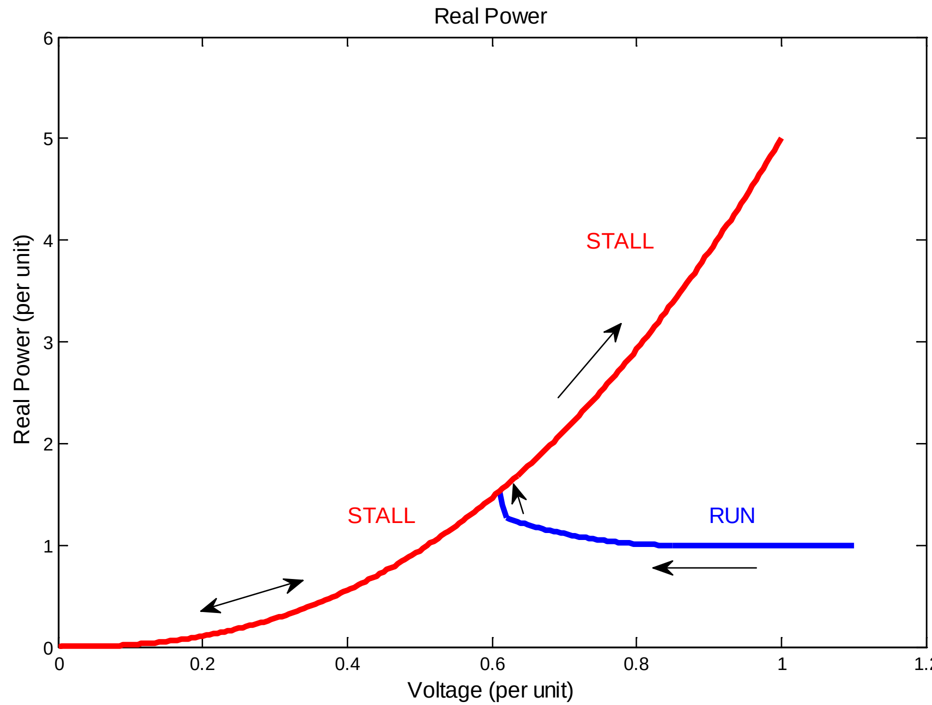
Single phase motor elec. torque

Load torque

Development of Initial Performance Model

- Motor stalls when voltage drops below V_{stall} for duration T_{stall}
  - V_{stall} ~ 0.52-0.6 pu
  - T_{stall} ~ 0.033 sec





Source: BPA

Electromagnetic Transient Simulations

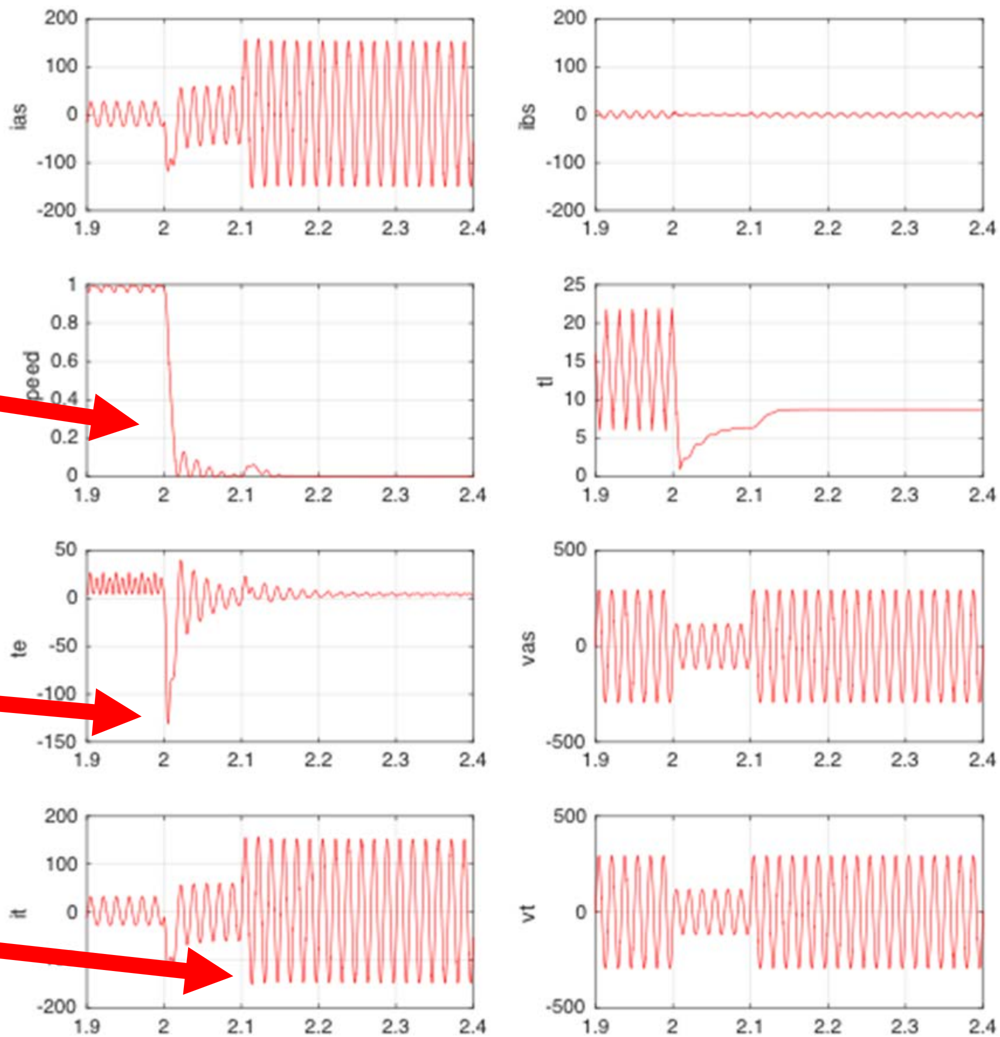
5 kW 1-ph A/C

H = 0.048 sec

Speed is pulled down very strongly by negative T_{elec}

Negative peak of electrical torque ~8x rated torque

Current by stalled motor 5x rated current



Source: J. Undrill

Electromagnetic Transient Simulations

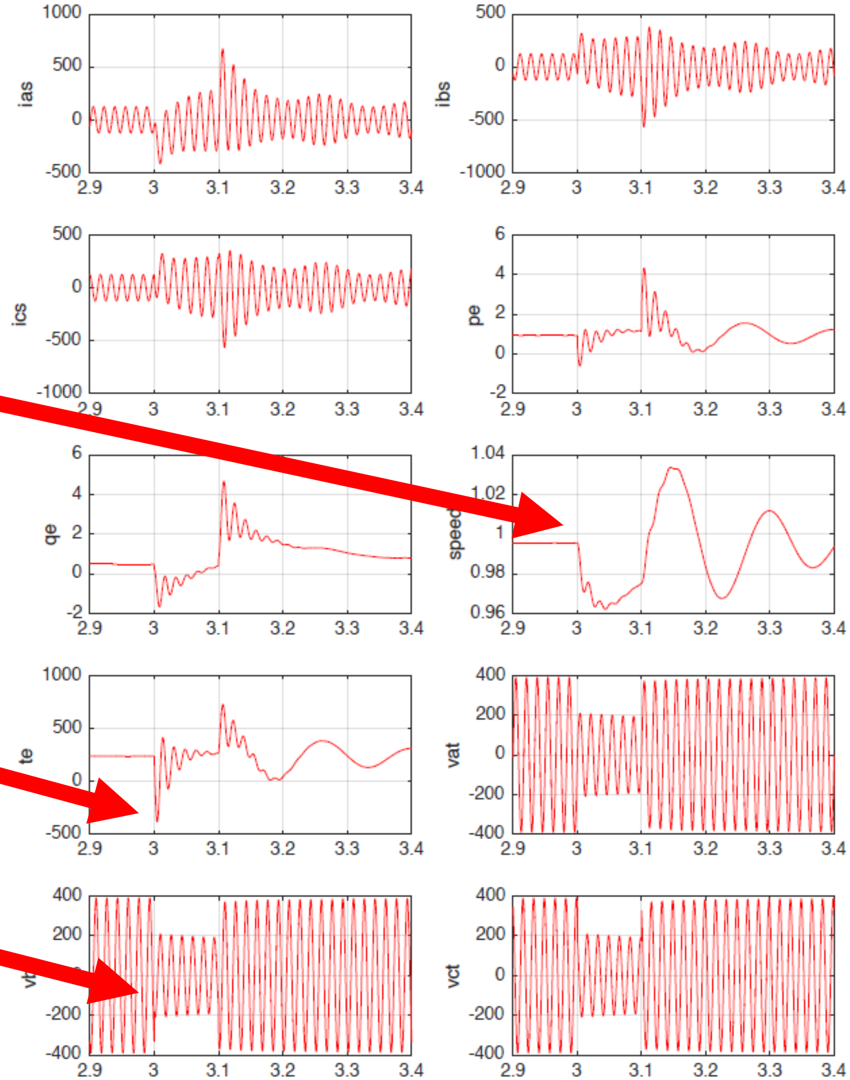
100 kVA 3-ph Motor

H = 0.3 sec

Speed minimally pulled down by negative T_{elec}

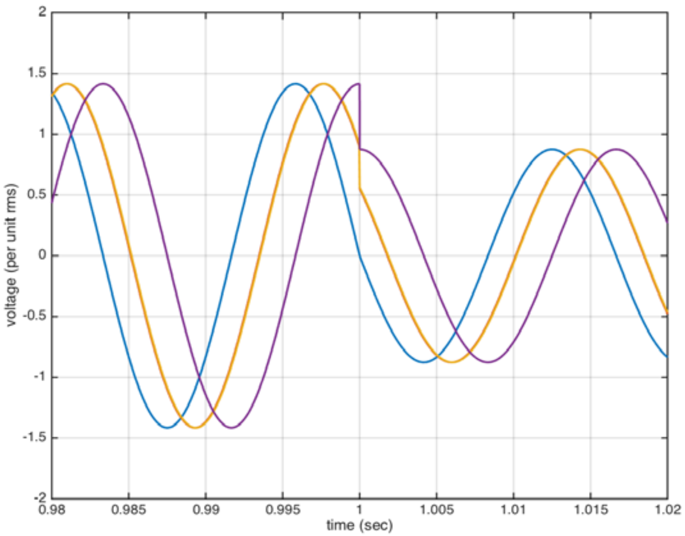
Negative peak of electrical torque ~1-2x rated torque

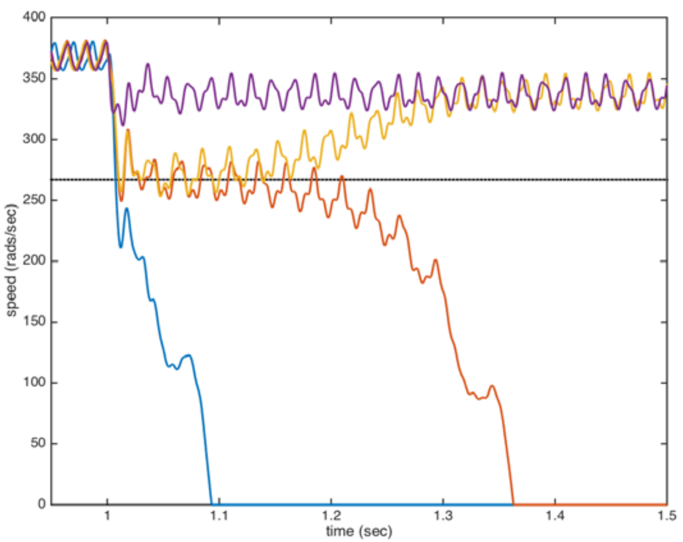
Current returns to near rated current



Source: J. Undrill

Point-on Wave Simulations

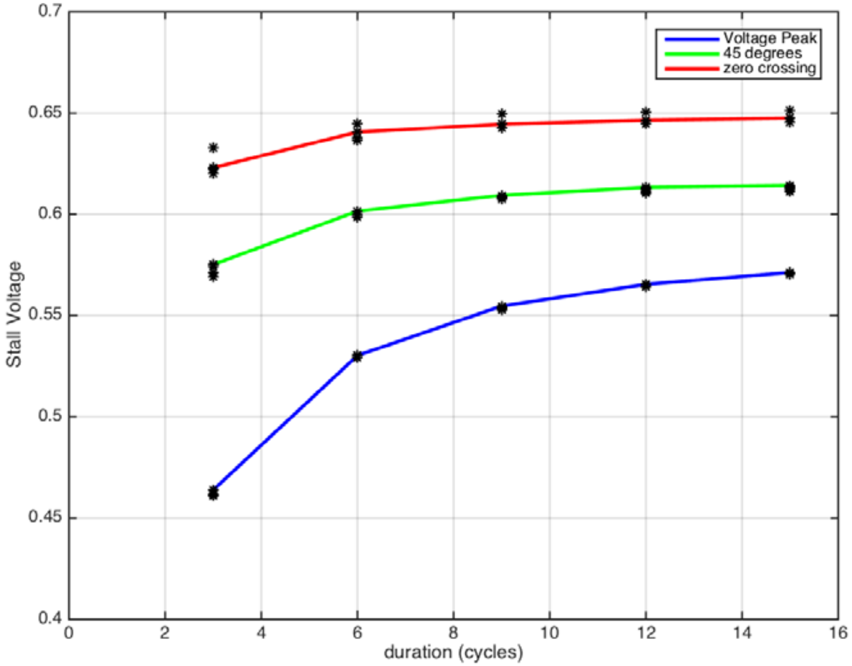


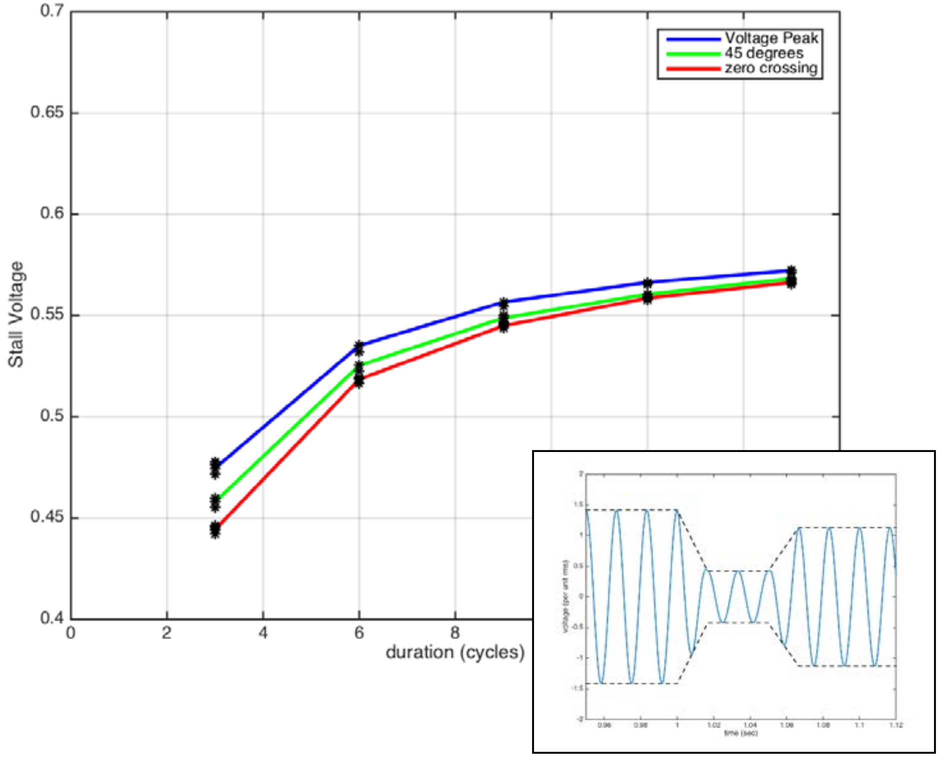


Source: Univ. Wisconsin

- "Common mode failure" of testing
  - Applied voltage sag at point-on-wave zero crossing in every test
- Instantaneous voltage drop to 0.62 pu for 3 cycles
  - Voltage zero crossing
  - Voltage peak
  - Voltage 45 deg point
- Worst case – zero crossing

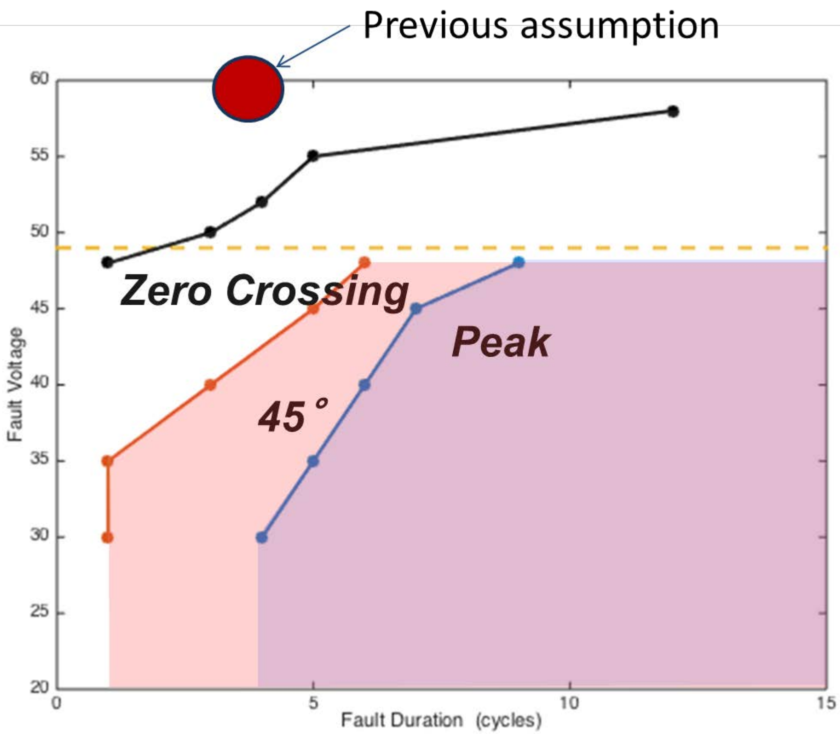
Stall Voltage vs. Point on Wave Simulation

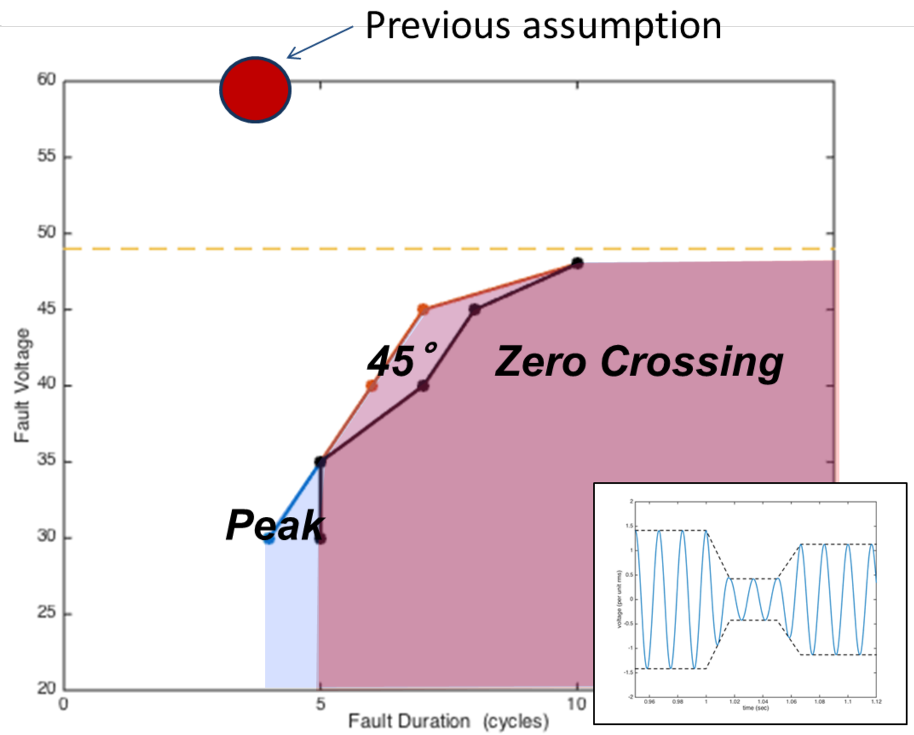




Source: Univ. Wisconsin

Stall Voltage vs. Point on Wave Testing





Source: Univ. Wisconsin, BPA

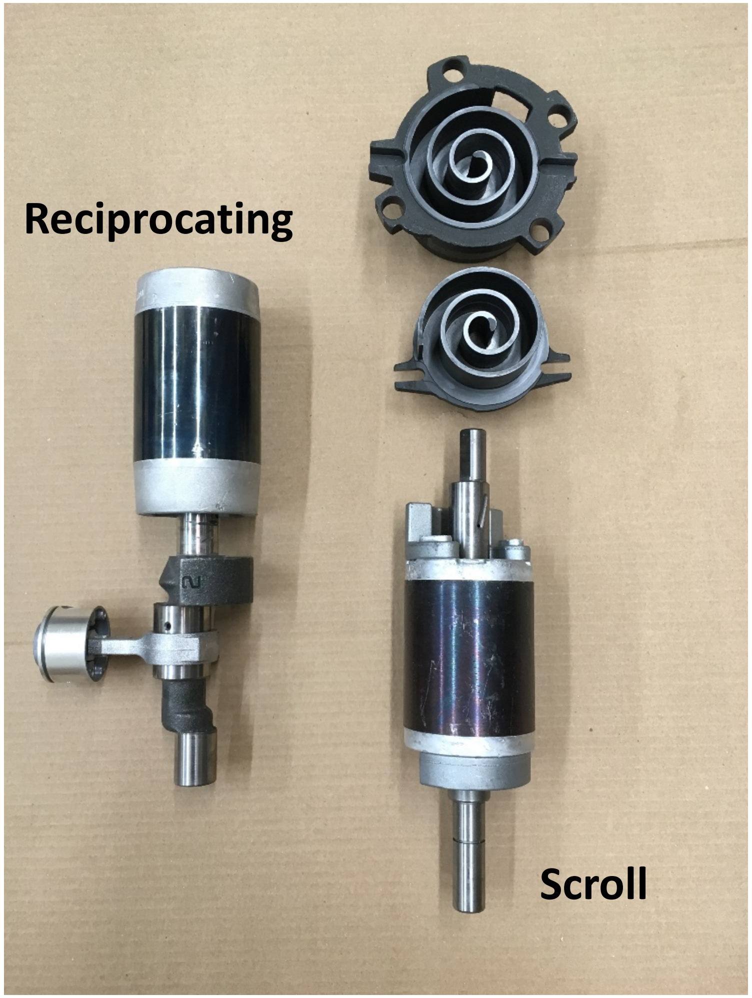
Scroll vs. Reciprocating

Scroll Compressors

- Vast majority of new compressors
- Better fault ride-through ability
- May run backwards after fault
  - ~1-1.25x rated current – not locked rotor – up to tens of minutes
- Estimated to be ~ 50% of A/C fleet today (*2015 NERC FIDVR Workshop*)

Reciprocating Compressors

- Majority of fleet until 2000s
- Disappearing due to energy efficiency requirements



Source: BPA

Reasonable Stall Voltage and Time

Simulation

	V_{stall} [pu]	T_{stall} [cycles]
Conservative	0.62	3
	0.63	4
	0.64	5
Moderate	0.56	3
	0.57	4
	0.59	5
Optimistic	**0.46**	**3**
	0.48	**4**
	0.52	**5**

Testing

	V_{stall} [pu]	T_{stall} [cycles]
Conservative	0.49	1
	0.5	2
	0.51	3
	0.53	4
Moderate	0.35	1
	0.37	2
	0.4	3
	0.42	4
Optimistic	**0.30**	**4**
	0.35	**5**
	0.4	**6**

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Reasonable Stall Voltage and Time

- Based on latest testing, simulation, and understanding of single-phase air-conditioners...

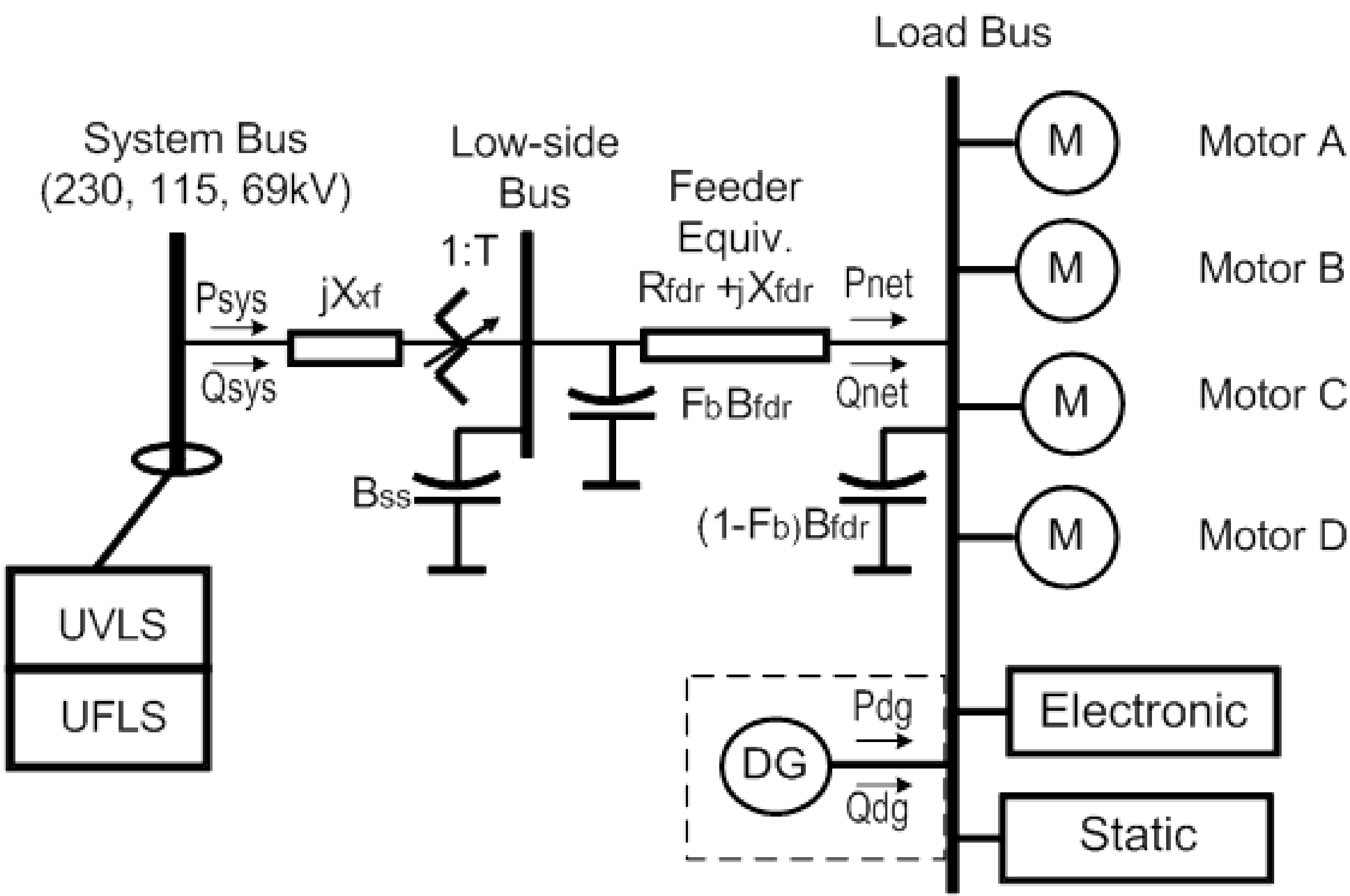
- Reasonable values of Vstall/Tstall

  V_{stall}: 0.40-0.45 pu

  T_{stall}: 2-4 cycles

- Sensitivity studies are key

Composite Load Model

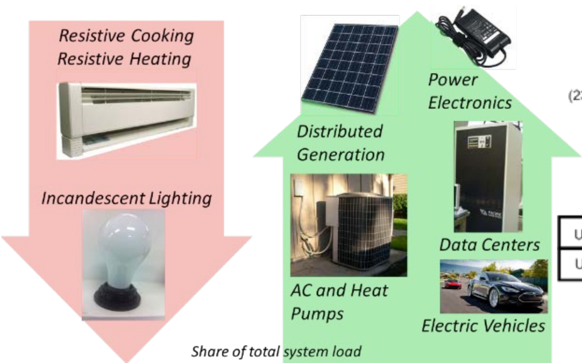


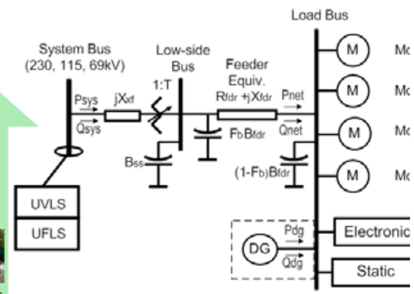
Meeting the Needs of TODAY for Dynamic Load Modeling

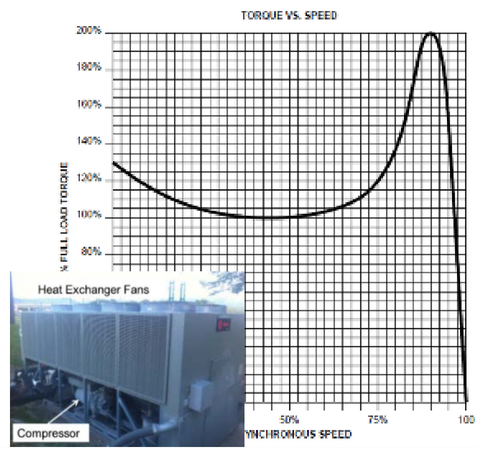
Addressing issues and practices with the existing dynamic load models

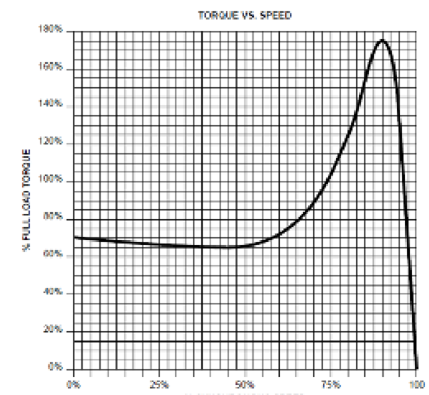
Technical Reference Document

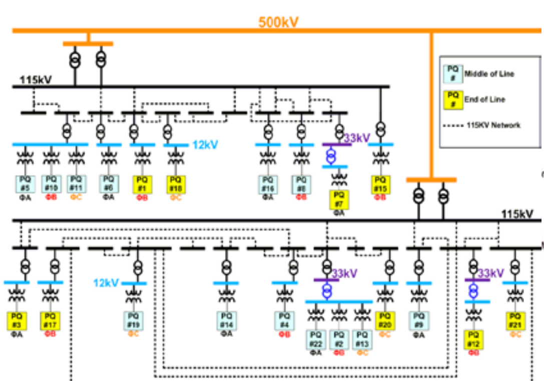
- Documents current state of dynamic load modeling
- Follow-up to the NERC FIDVR Workshop in September 2015
- Document approved by NERC PC December 2016

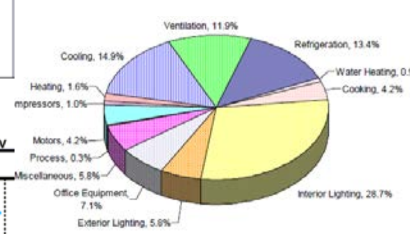


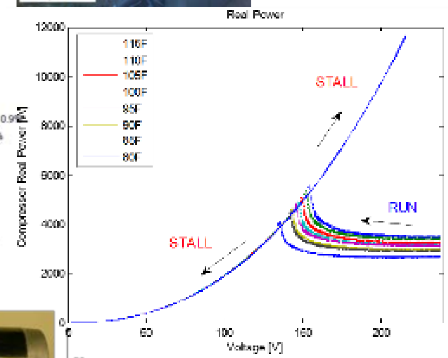


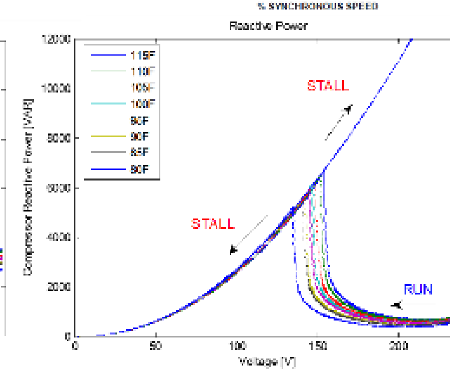






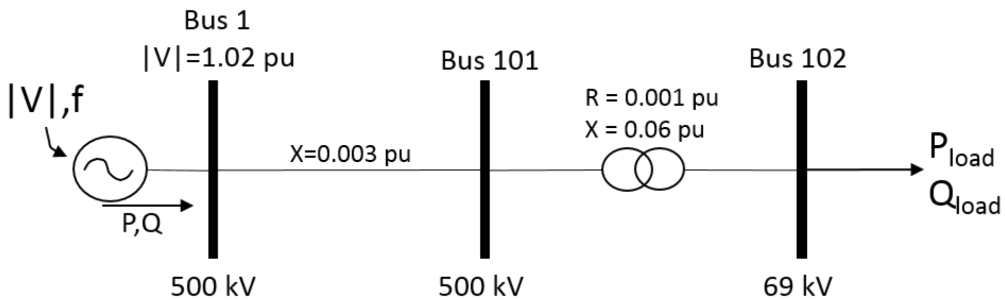




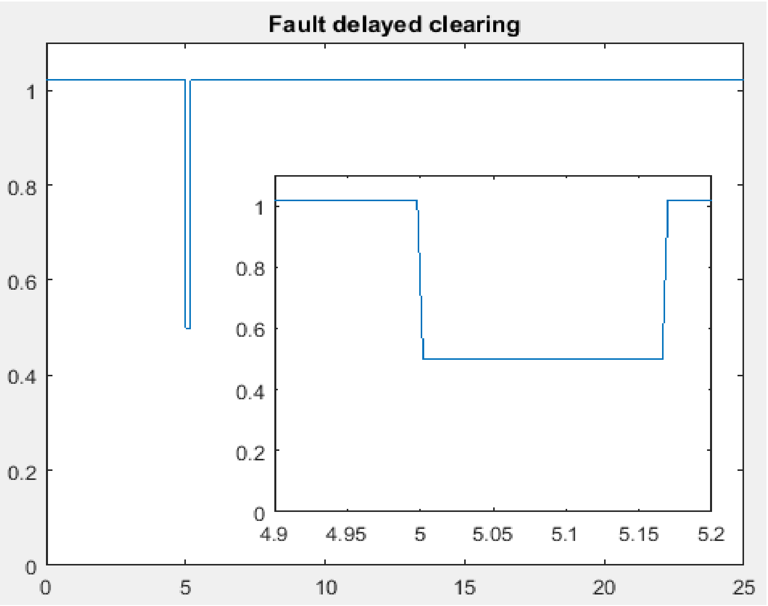


Load Model Benchmarking

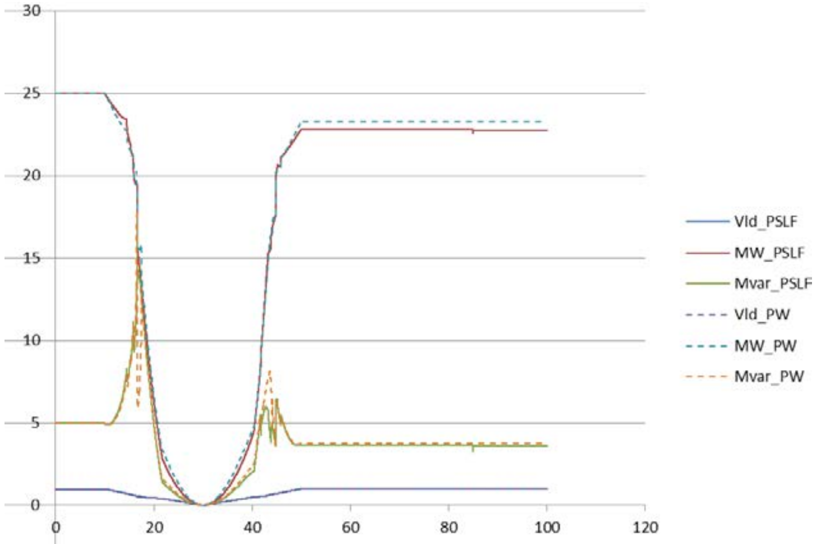
- Initial LMTF member and vendor benchmarking
- NERC LMTF default data set tested using standard test events
- EPRI testing and supporting this effort
- Results being compiled to identify any discrepancies
- Fixing any software implementation issues identified



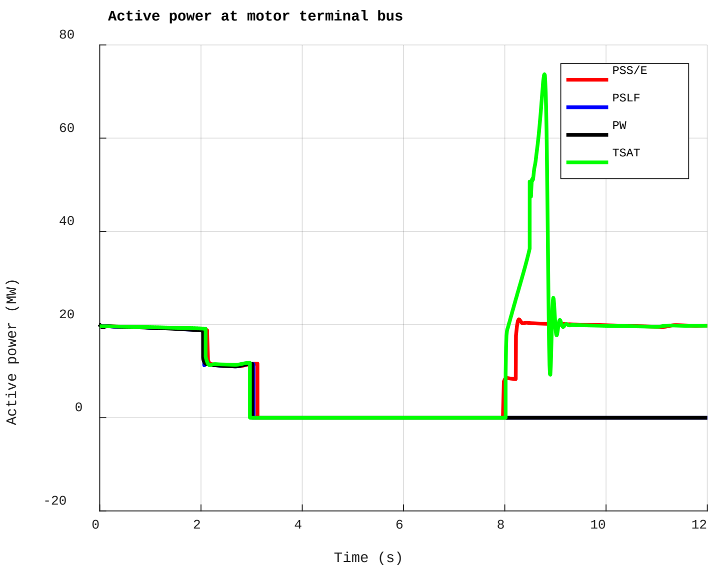
Voltage		Flow (Measured at From End)			
Bus	V_{mag} [pu]	From Bus	To Bus	Flow MW	Flow MVar
1	1.020	102	101	165.0	82
101	1.020	101	1	165.3	90.1
102	0.999				



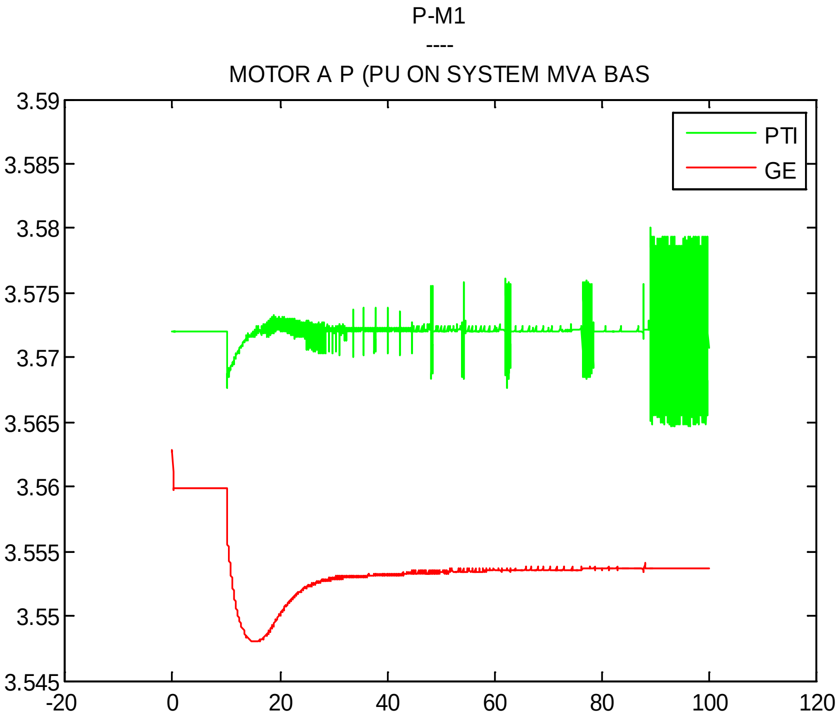
Load Model Benchmarking



Source: PowerWorld

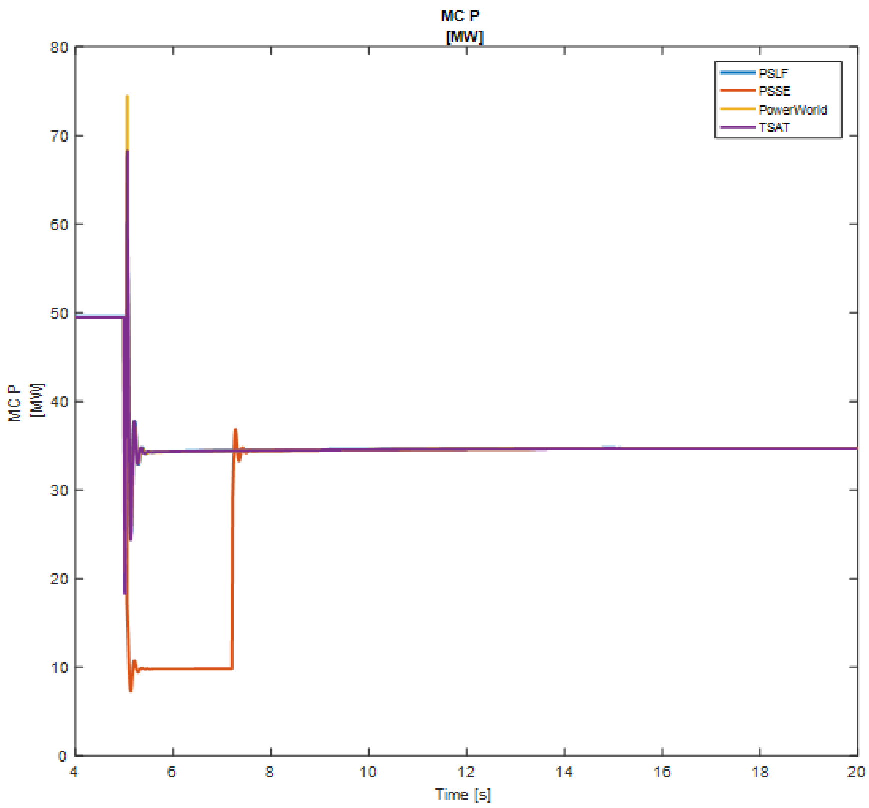


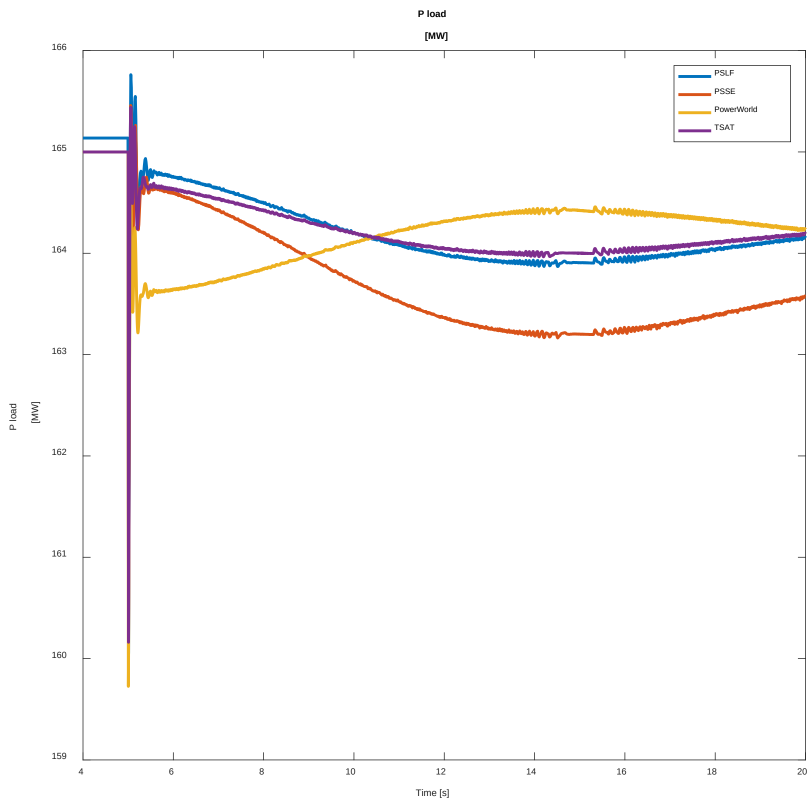
Source: EPRI



Source: PacifiCorp

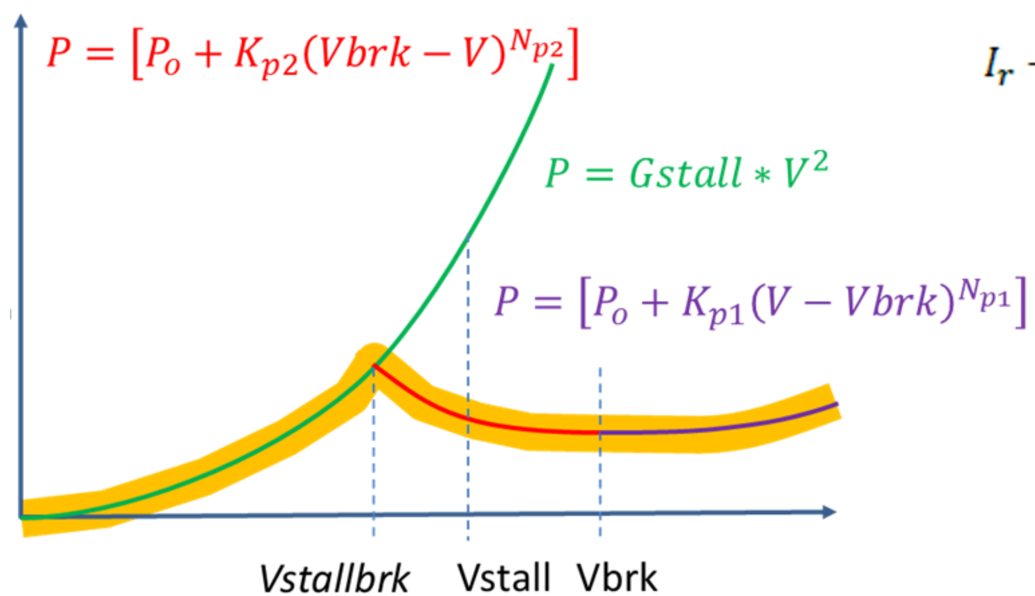
Load Model Benchmarking

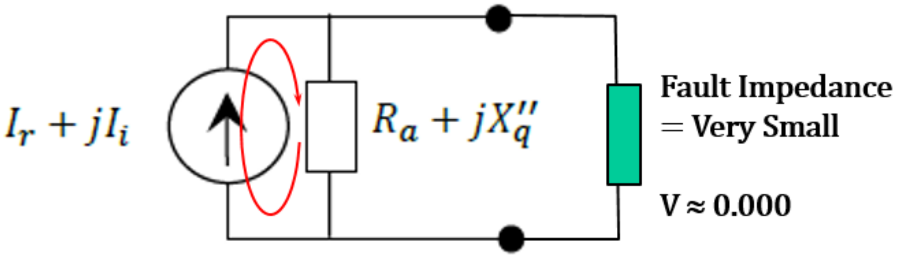




Network Boundary Equations & Initialization

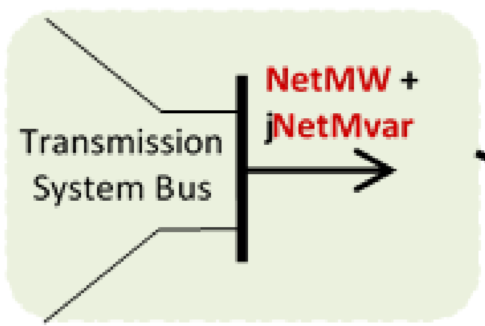
- Standardized procedures for software initialization
- Familiarize and standardize practices for dealing with current sources in dynamics – motor model numerical issues
- Overcome “crashing” issues





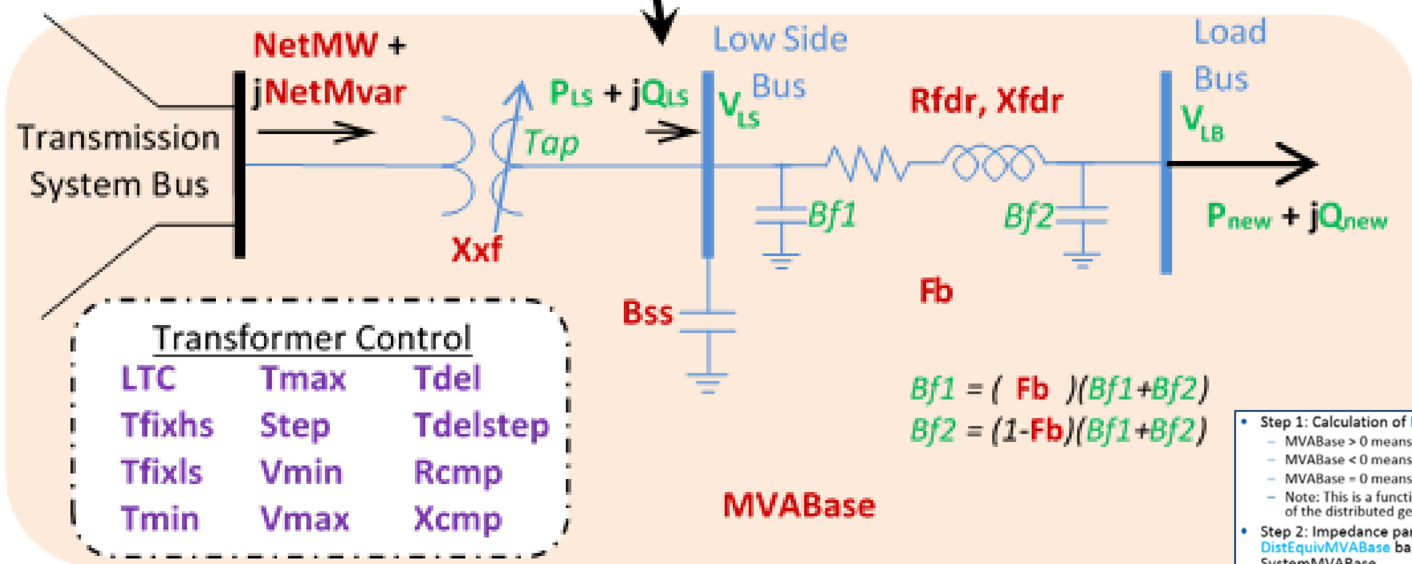
Source: PowerWorld

Common Initialization & Network Boundary Equations



The internal model used by the transient stability numerical simulation structurally does the following.

1. Creates two buses called Low Side Bus and Load Bus
2. Creates a transformer between Transmission Bus and Low Side Bus
3. Creates a capacitor at the Low Side Bus
4. Creates a branch between Low Side Bus and Load Bus
5. Moves the Load from the Transmission Bus to the Load Bus



- Step 1: Calculation of DistEquivMVABase
  - MVABase > 0 means DistEquivMVABase = MVABase
  - MVABase < 0 means DistEquivMVABase = Abs(**NetMW**/MVABase)
  - MVABase = 0 means DistEquivMVABase = Abs(**NetMW**/0.8)
  - Note: This is a function of NetMW, so that means MW – DistMW of the distributed generation
- Step 2: Impedance parameters are given on this DistEquivMVABase base, so convert them to the SystemMVABase
  - **Xxf** = **Xxf** * *SystemMVABase*/ *DistEquivMVABase*.
    Rfdr = **Rfdr** * *SystemMVABase*/ *DistEquivMVABase*.
    Xfdr = **Xfdr** * *SystemMVABase*/ *DistEquivMVABase*.
    Rcmp = **Rcmp** * *SystemMVABase*/ *DistEquivMVABase*.
    Xcmp = **Xcmp** * *SystemMVABase*/ *DistEquivMVABase*.
    Bss = **Bss** / *SystemMVABase** *DistEquivMVABase*.

Source: PowerWorld

Robust Default Data Sets

- Developed robust default data sets for use across regions as starting point
  - Suitable and reasonable parameters for protection
  - Can be modified with regional data, composition data

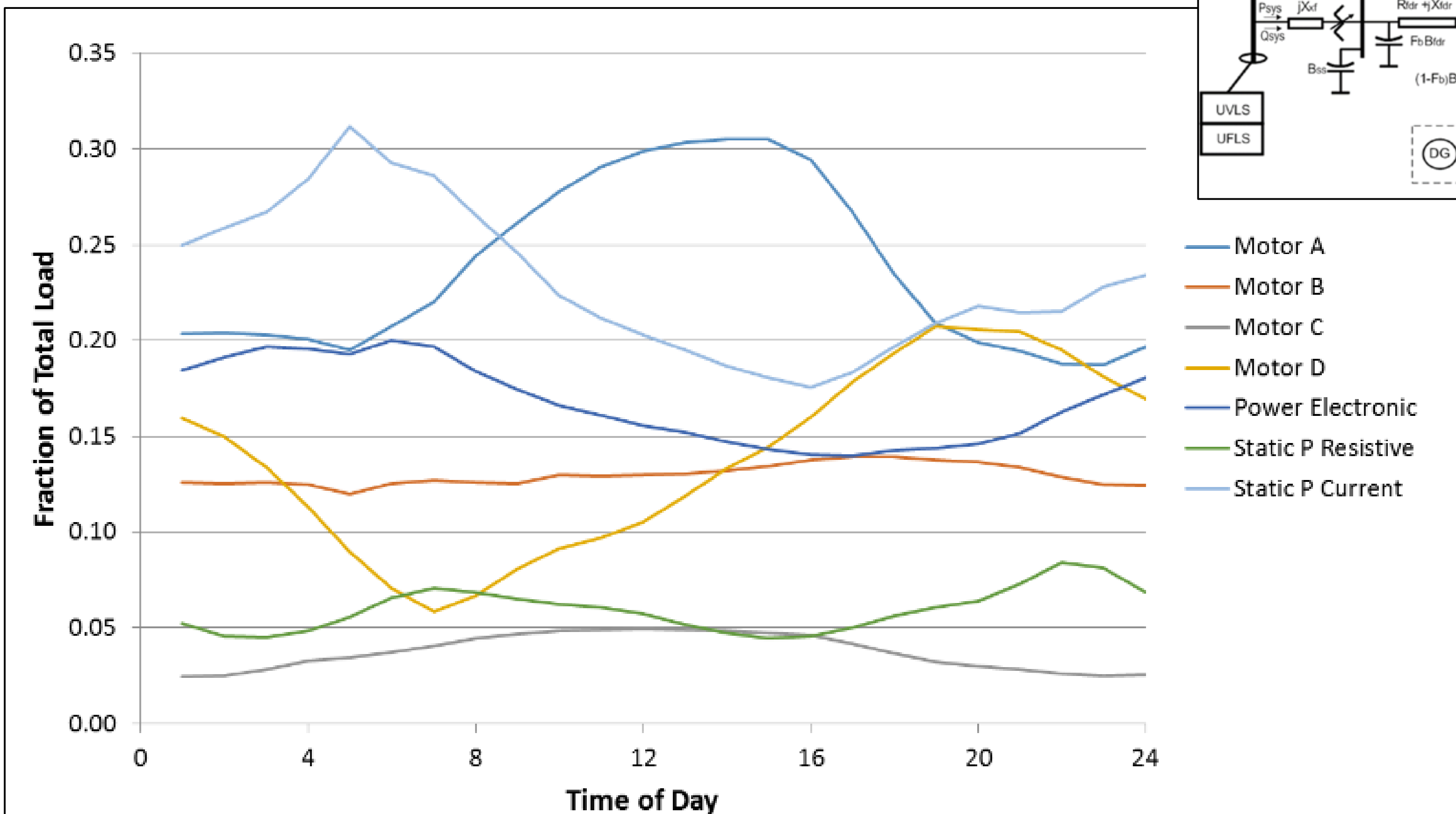
DEFAULT PARAMETERS FOR COMPOSITE LOAD MODEL
PHASE 1 IMPLEMENTATION
PSS®E Implementation - CMLD Model Parameters

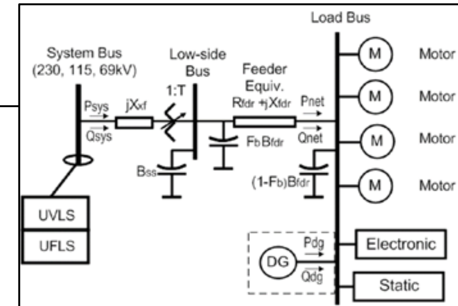
Color Code:

(gray)	Parameters don't change
(green)	Parameters are generally set once and left alone
(orange)	Parameters require engineering judgment/input
Value	Sensitivity analysis may be required

CON	Description	Default Value	Higher Limit	Lower Limit	Notes
J	Load MVA Base	-1.25			Load Factor = |Load MW / MVA Base|
J+1	Substation shunt B	0			Assumed default feeder impedance and transformer fixed tap settings.
J+2	Rfdr	0.04			
J+3	Xfdr	0.04			
J+4	Fb	0.75			
J+5	Xxf	0.08			
J+6	Tfixhs	1			
J+7	Tfixls	1			
J+8	LTC	0			Based on TO T/D LTCs
J+9	Tmin	0.9			Assumed generic transformer LTC tap adjustments
J+10	Tmax	1.1			
J+11	Step	0.00625			
J+12	Vmin	1.025			These are based on the utility practice for voltage set point and LTC control timing.
J+13	Vmax	1.04			
J+14	TD	30			
J+15	TC	5			
J+16	Rcmp	0			
J+17	Xcmp	0			
J+18	FmA	0.2	0.2	0.15	End-Use Load Dependent
J+19	FmB	0.1	0.1	0.15	End-Use Load Dependent
J+20	FmC	0.05	0.05	0.05	End-Use Load Dependent
J+21	FmD	0	0.25	0.15	End-Use Load Dependent
J+22	Fel	0.15	0.1	0.2	End-Use Load Dependent
J+23	Pfel	1	1	1	Assume unity power factor electronic loads
J+24	Vd1	0.65	0.7	0.6	Assumed trip points for power electronic loads based on laboratory testing

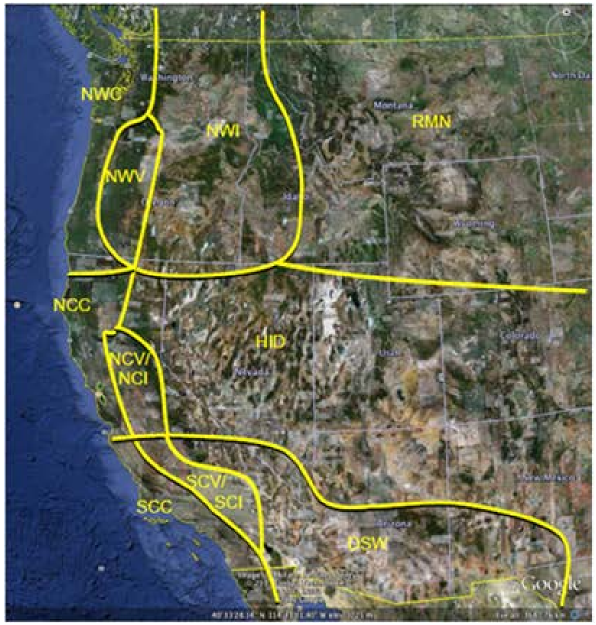
Developing Load Composition Data





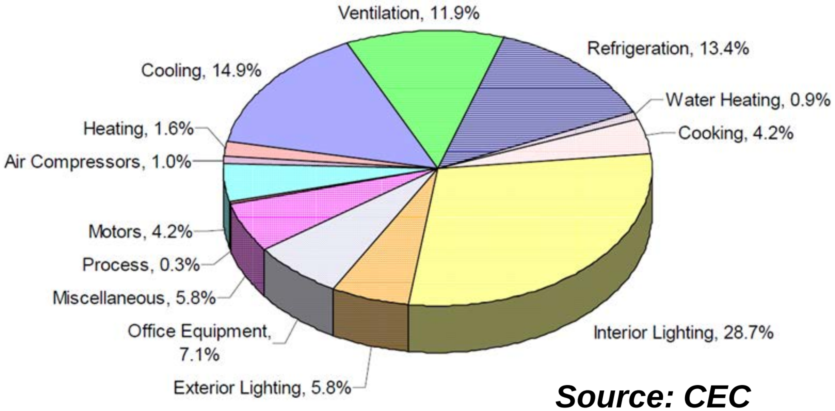
Source: WECC

Developing Load Composition Data

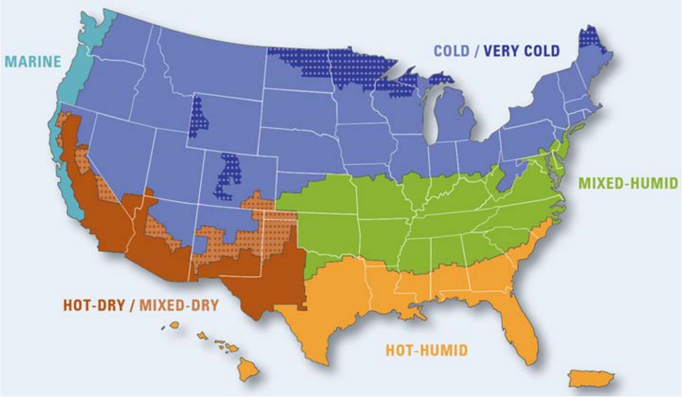


ID	Climate Zone	Representative City
NWC	Northwest Coast	Seattle, Vancouver BC
NWV	Northwest Valley	Portland OR
NWI	Northwest Inland	Boise, Tri-Cities, Spokane
RMN	Rocky Mountain North	Calgary, Montana, Wyoming
NCC	Northern California Coast	Bay Area
NCV	Northern California Valley	Sacramento
NCI	Northern California Inland	Fresno
SCC	Southern California Coast	LA, San Diego
SCV	Southern California Valley	LA, San Diego
SCI	Southern California Inland	LA, San Diego
DSW	Desert Southwest	Phoenix, Riverside, Las Vegas
HID	High Desert	Salt Lake City, Albuquerque, Denver, Reno

Source: WECC



Source: CEC



Source: DOE

Reliability Guideline: Load Composition

End-Use Load Data

- Billing Data
- Regional Data
- Historical SCADA
- End-Use Load Surveys
- Energy Efficiency Data
- Energy Information Administration (EIA) Data

Load Classification

- Rules of Association
- Residential
- Commercial
- Industrial
- Agricultural
- Manufacturing

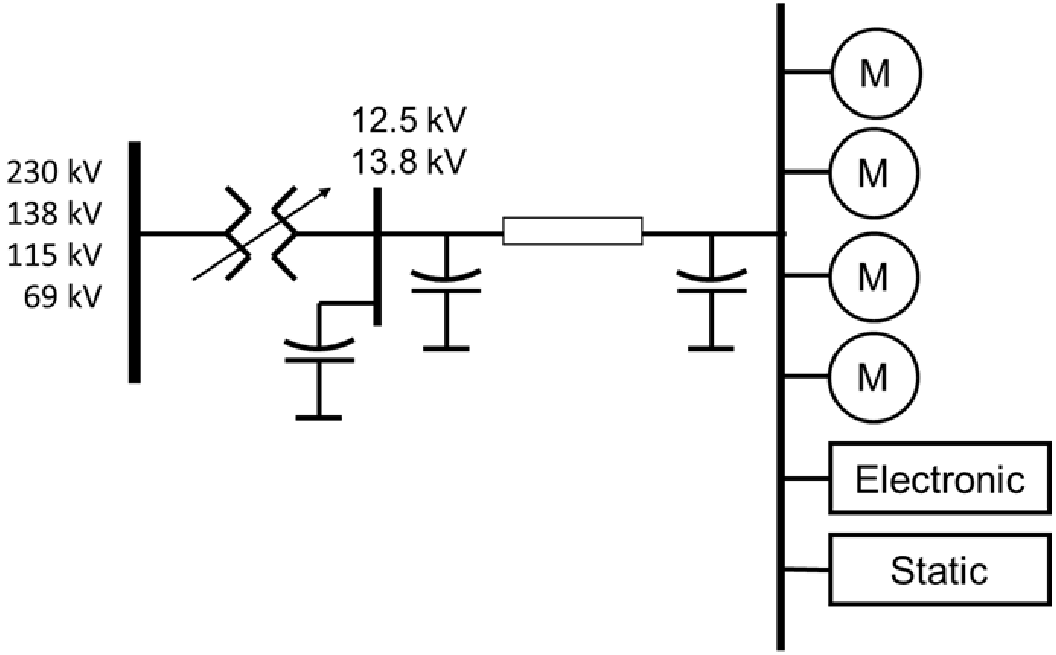
Model Parameters

- Induction Motor Load(s)
- Lighting
- Power Electronics
- Distributed Generation
- Static Load Classification
- Feeder Impedance
- Protection Settings

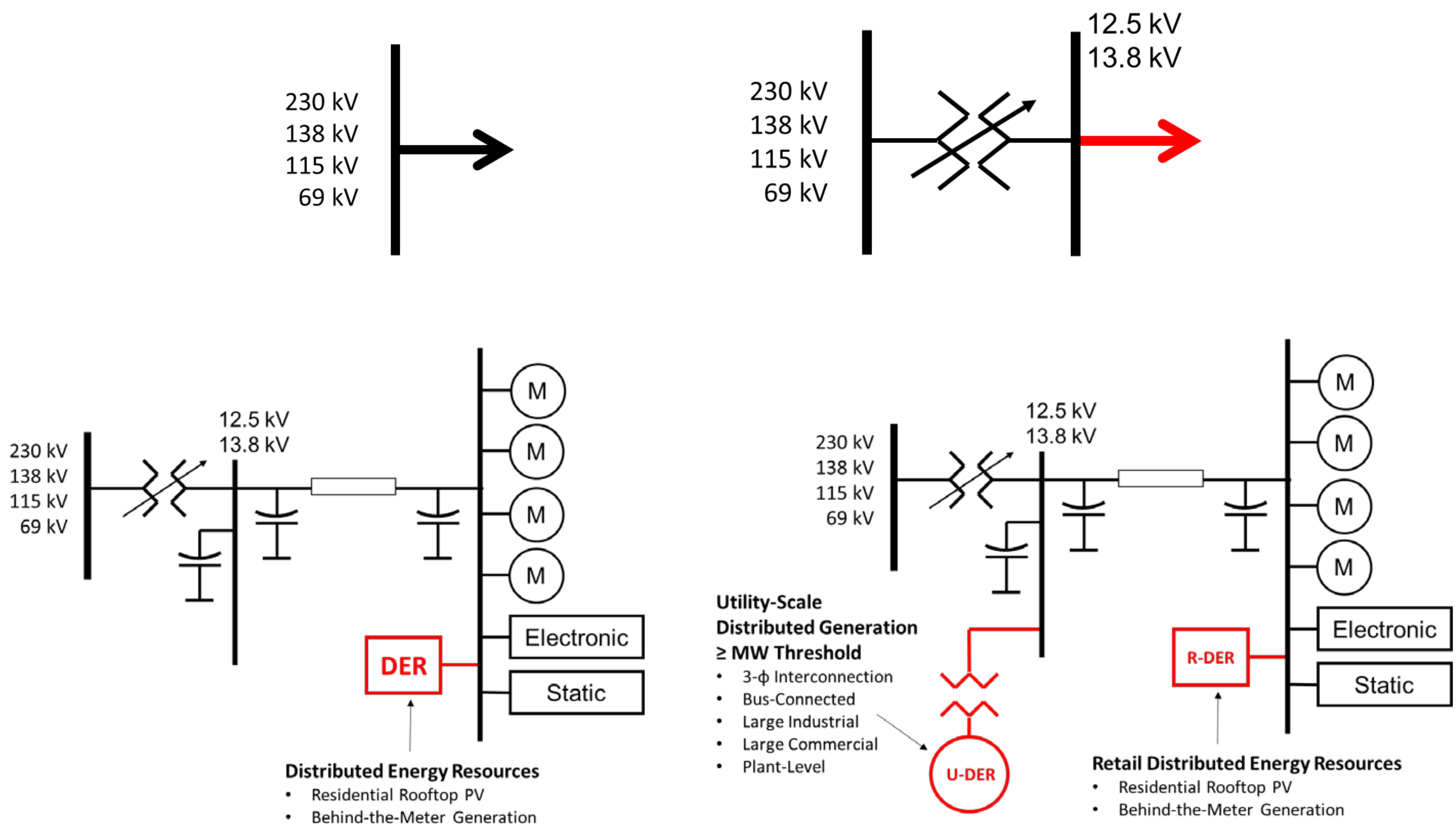
Building Type	% Large-Motor	% Small-Motor	% Discharge Lighting	% Constant Power	% TX Exciting Current	Kp of Remaining	Branch R	Branch X
Church	0	0.4	0.1	0.1	0	1.25	0.04	0.12
State Building	0.2	0.4	0.2	0.1	0	1.25	0.04	0.12
County Municipal	0.2	0.4	0.2	0.1	0	1.25	0.04	0.12
Industrial	0.8	0.1	0.1	0	0	1.25	0.04	0.12
Large Commercial	0.5	0.2	0.1	0.1	0	1.25	0.04	0.12
Large Comm./Industrial	0.5	0.4	0.1	0	0	1.25	0.04	0.12
Small Commercial	0.3	0.4	0.2	0.1	0	1.25	0.04	0.12
Region 1 Residential	0	0.7	0	0.1	0	1.25	0.04	0.12
Region 2 Residential	0	0.6	0	0.2	0	1.25	0.04	0.12
Lighting Only	0	0	1	0	0	1.25	0.04	0.12
Flat Load	0.15	0.45	0.2	0.1	0	1.25	0.04	0.12
Resale	0	0.6	0	0.2	0	1.25	0.04	0.12

Modeling Distributed Energy Resources in Dynamic Load Models

- Developing Reliability Guideline on modeling DER in dynamic load models and powerflow models
- Coordination with NERC DERTF efforts



Modeling Distributed Energy Resources in Dynamic Load Models



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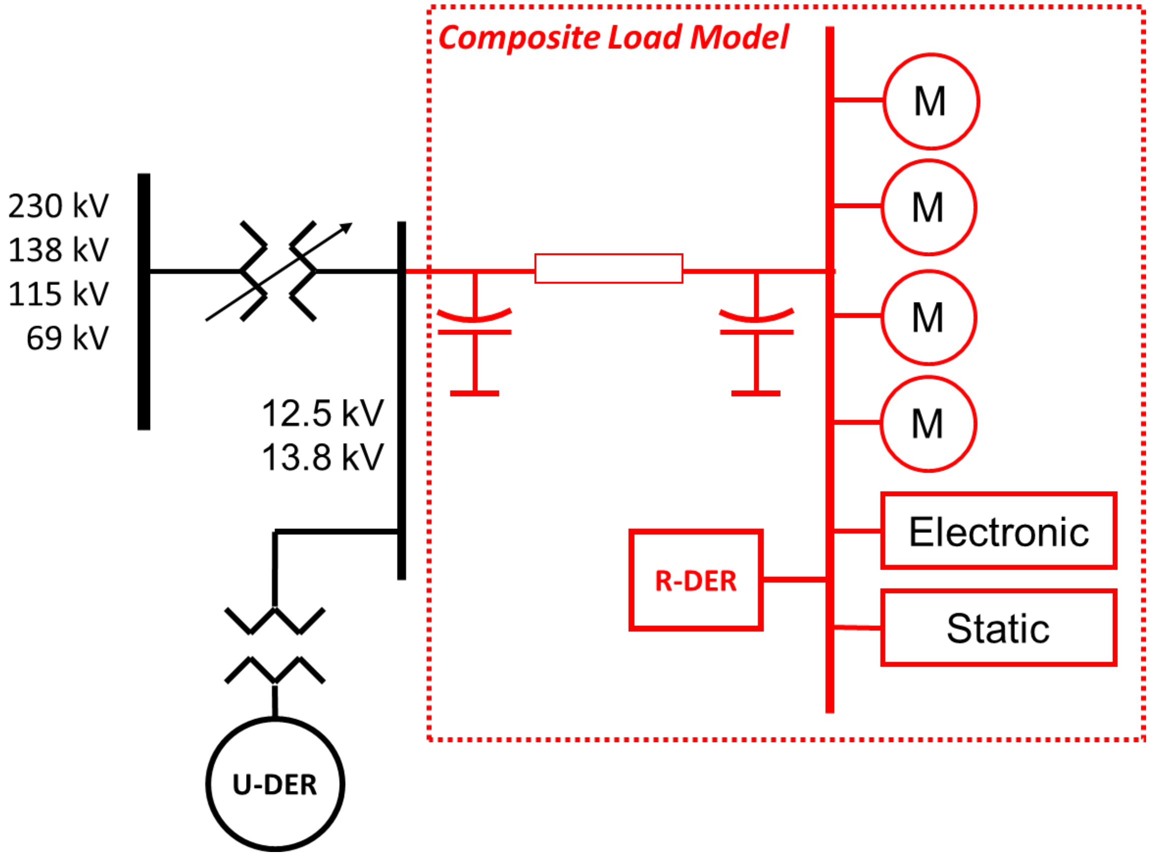
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Reliability Guideline: DER in Dynamic Load Models



Source: PowerWorld

	Number of Bus	Name of Bus	Area Name of Load	Zone Name of Load	ID	Status	MW	Mvar	MVA	S MW	S Mvar	Dist Status	Dist MW Input	Dist Mvar Input	Dist MW	Dist Mvar	Net Mvar	Net MW
1	2	Two	Top	1	1	Closed	80.00	20.00	82.46	80.00	20.00	Closed	40.00	0.00	40.000	0.000	20.000	40.000
2	3	Three	Top	1	1	Closed	220.00	40.00	223.61	220.00	40.00	Open	110.00	0.00	0.000	0.000	40.000	220.000
3	4	Four	Top	1	1	Closed	160.00	30.00	162.79	160.00	30.00	Closed	80.00	0.00	80.000	0.000	30.000	80.000
4	5	Five	Top	1	1	Closed	260.00	40.00	263.06	260.00	40.00	Open	130.00	0.00	0.000	0.000	40.000	260.000
5	6	Six	Left	1	1	Closed	400.00	0.00	400.00	400.00	0.00	Closed	200.00	0.00	200.000	0.000	0.000	200.000
6	7	Seven	Right	1	1	Closed	400.00	0.00	400.00	400.00	0.00	Closed	200.00	0.00	200.000	0.000	0.000	200.000

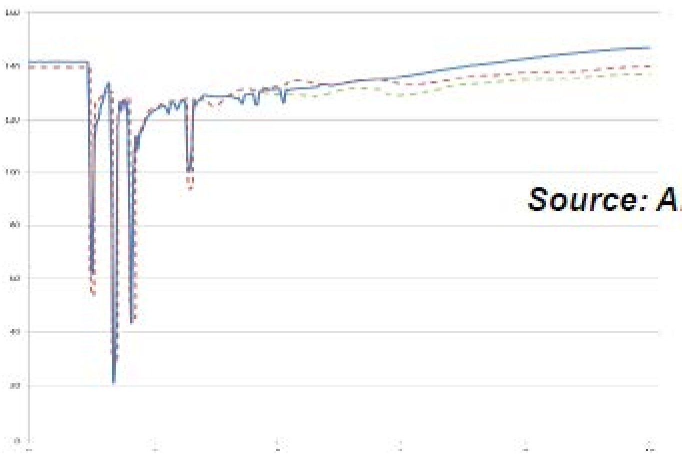
Reliability Guideline: DER in Dynamic Load Models

- **Utility-Scale Distributed Energy Resources (U-DER):** distributed energy resources directly connected to the distribution bus or connected to the distribution bus through a dedicated, non-load serving feeder. These resources are specifically three-phase interconnections, and can range in capacity, for example, from 0.5 to 20 MW although facility ratings can differ.
- **Retail-Scale Distributed Energy Resources (R-DER):** distributed energy resources that offset customer load. These DER include residential, commercial, and industrial customers. Typically, the residential units are single-phase while the commercial and industrial units can be single- or three-phase facilities.

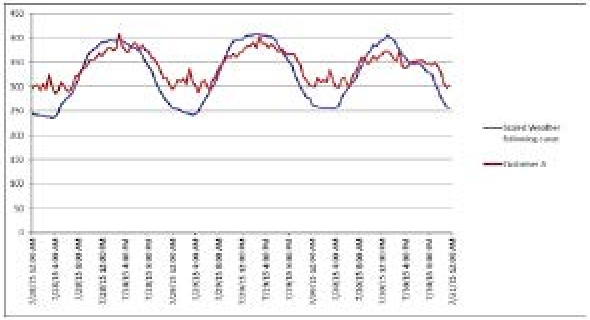
Table 1: Example of U-DER and R-DER Requirements

Criteria	Description	Threshold
U-DER Modeling	Gross aggregate nameplate rating of an individual U-DER facility directly connected to the distribution bus or interconnected to the distribution bus through a dedicated, non-load serving feeder	___ MVA
R-DER Modeling	Gross aggregate nameplate rating of all connected R-DER resources that offset customer load including residential, commercial, and industrial customers	___ MVA

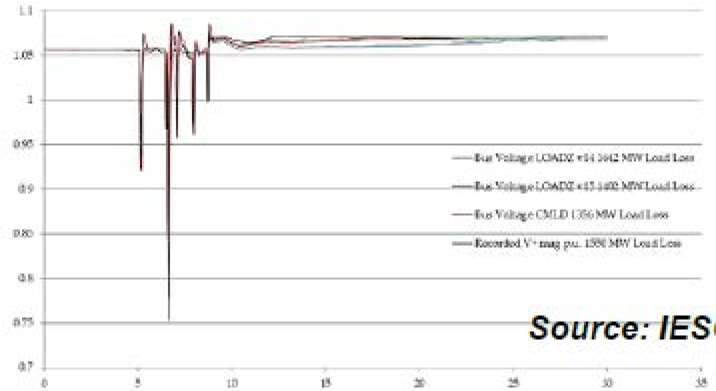
Utility Forum: Dynamic Load Modeling



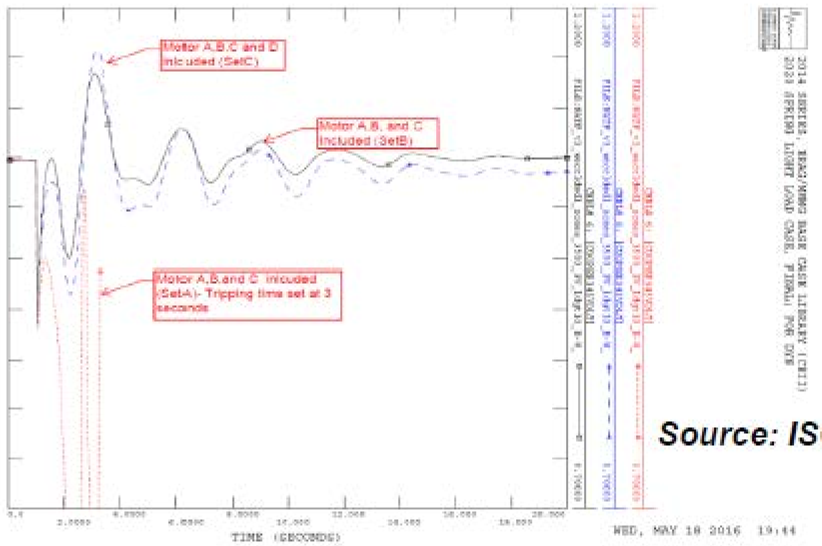
Source: AEP



Source: PECO



Source: IESO

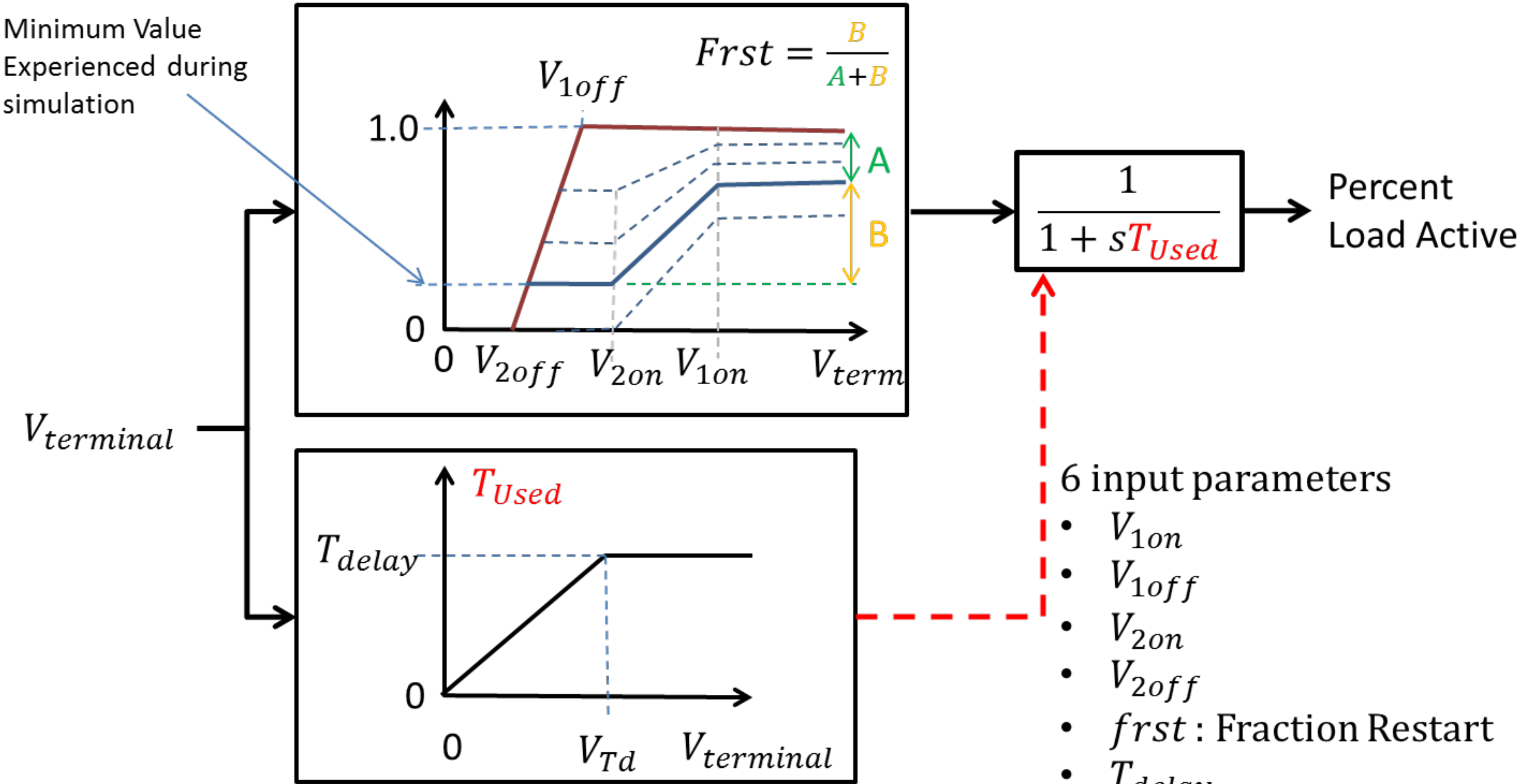


Source: ISO-NE

Meeting the Needs of TOMORROW for Dynamic Load Modeling

Addressing issues and practices with future dynamic load models

Progressive Stalling and Tripping



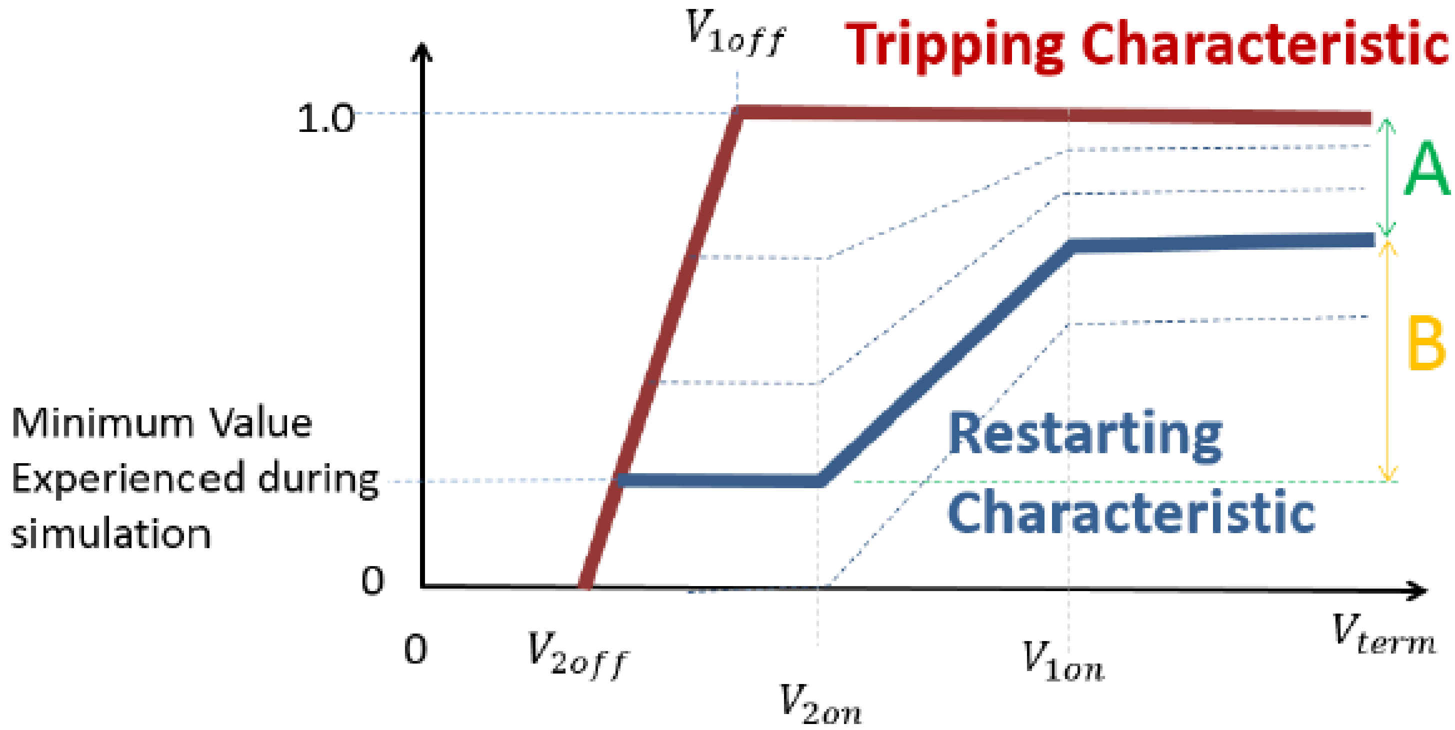
6 input parameters

- V_{1on}
- V_{1off}
- V_{2on}
- V_{2off}
- $frst$: Fraction Restart
- T_{delay}
- V_{Td}

Source: PowerWorld

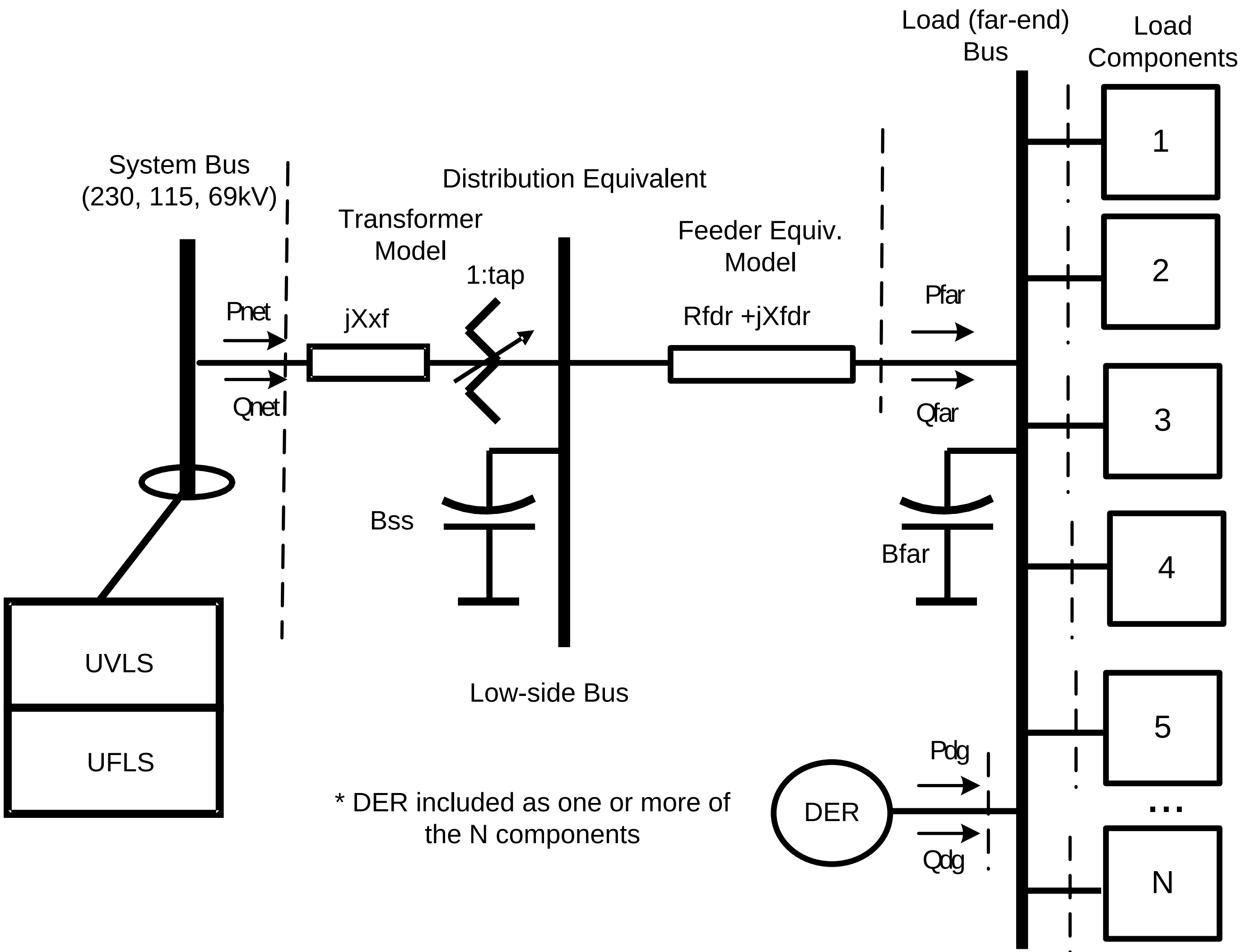
Progressive Stalling and Tripping

$$Frst = \frac{B}{A+B}$$



Source: PowerWorld

Efficient Data Format & Model Management



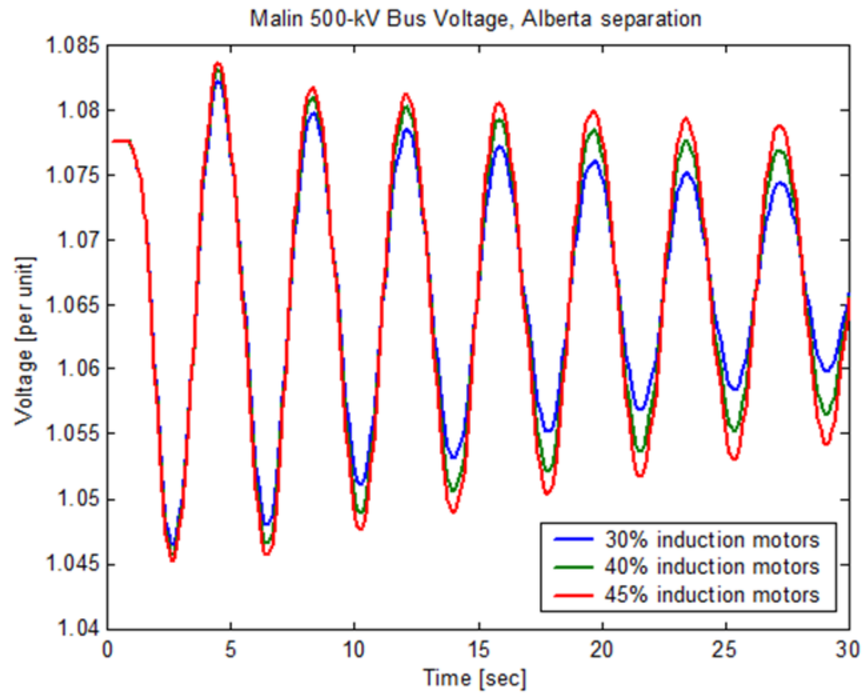
Efficient Data Format & Model Management

```
cmpldw2 11  "LOAD-CMP" 230.00 "MC" : #1 mva=-0.8 /
   cmp_dist  -50              /
   cmp_dgpv  -1001 1.0        /
   cmp_mot3  -301  0.2        /
   cmp_mot3  -302  0.1        /
   cmp_mot3  -303  0.1        /
   cmp_1pac  -401  0.2        /
   cmp_stat  -101  -1.        /
   cmp_elec  -201  0.2
```

```
_cmpldw2 -55 "NCI_RES" 0  :  #1  mva=-0.9 /
   "Pmin"  50. "Pfmin"  0.7  "Vmin"  0.8/
   cmp_dist  -50  /
   cmp_dgpv  -1001 1.0  /
   cmp_mot3  -301  0.2  /
   cmp_mot3  -302  0.1  /
   cmp_mot3  -303  0.1  /
   cmp_1pac  -401  0.2  /
   cmp_stat  -101  -1.  /
   cmp_elec  -201  0.2
```

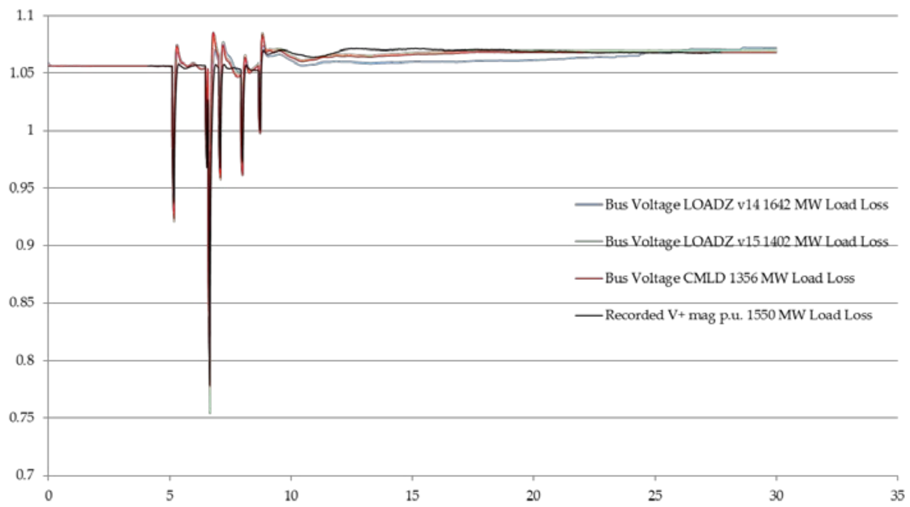
Dynamic Load Modeling in Real-Time Stability Analysis

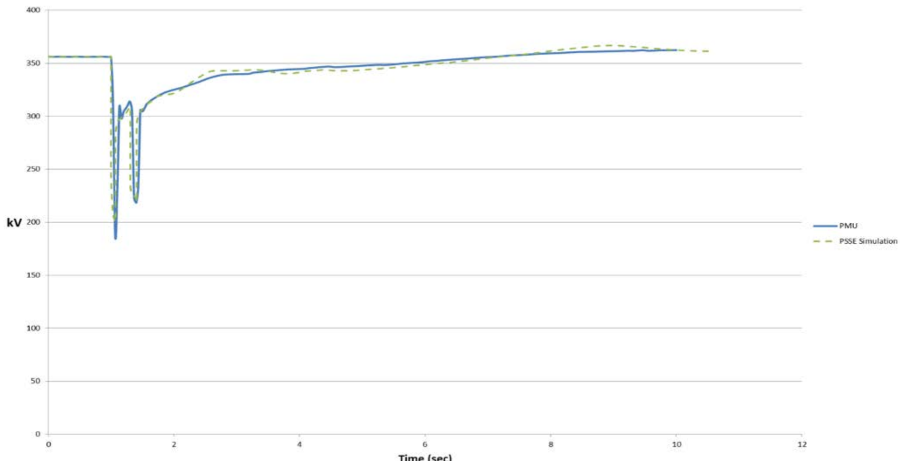
- Why do we ignore real-time modeling practices?
- Why do we require induction motor load in planning studies but not in real-time studies?
- What are the limitations in moving towards inclusion of induction motor load in real-time models?
- How do we proceed cautiously?



Event Recreation and Model Validation

- Model can be tuned to accurately represent actual system disturbances for event forensics





- Model used for planning studies is not expected to match traces perfectly – should capture the event in principle

Closing Remarks

- Evolution of end-use loads continuing to evolve
- Increasing DER penetrations, need for modeling practices
- Composite load modeling
  - Reference material for understanding model and parameters
  - Default data sets
  - Robust implementation
  - Used for thousands of transient stability studies effectively
- Load composition data
- Validation and sensitivity analysis

Wrap Up

- Participation in NERC LMTF
  - Email Ryan Quint (ryan.quint@nerc.net) to get added to LMTF Roster
  - Encourage anyone working in this area to participate, particularly utility planners and modelers

- Thank you for your interest in dynamic load modeling and the NERC LMTF!

Questions?