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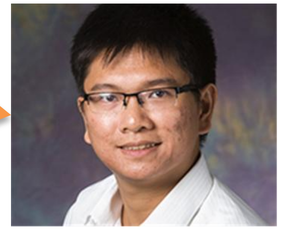

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Complexity Analysis for PMU Measurement-based Load Modeling

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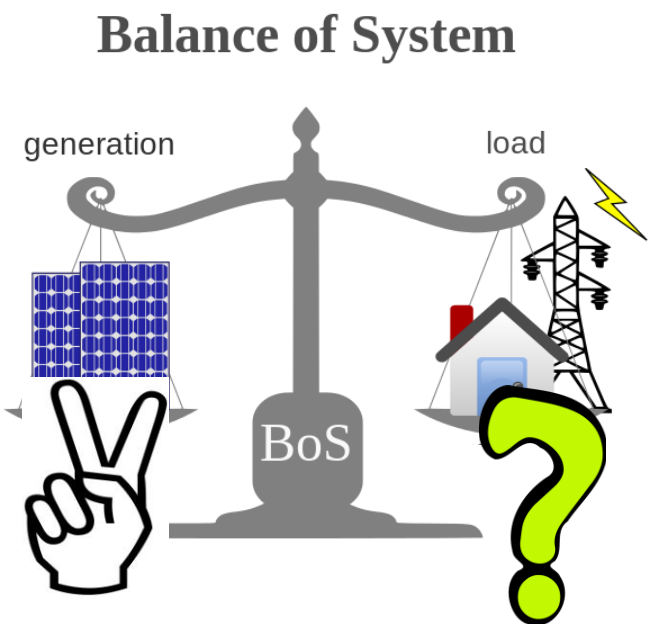
Motivation

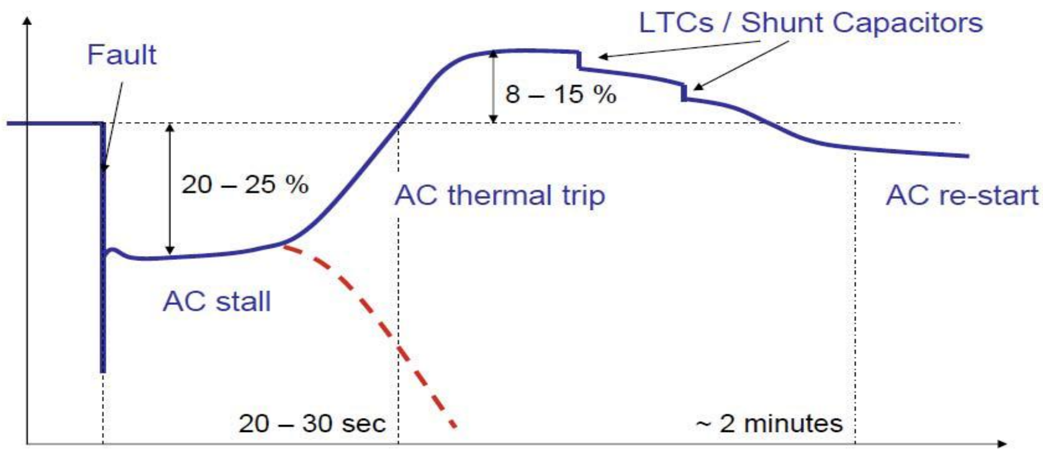
- Transient stability is key in many current analyses, and is being proposed to replace steady state contingency analysis
  - Operations: accurate dynamic models will be needed that reflect the current grid state in real time so operators can perform appropriate controls to ensure grid stability
  - Planning: fast models needed to reduce computation time and allow case studies with more dimensions
- Load models have traditionally been neglected
- Many dynamic studies attribute uncertainty of their solutions to load models



Source: wikipedia

Measurement-based load modeling

- **Goal:** accurate dynamic load models for transient stability studies
- Increasing interests in a measurement-based load modeling framework
- Thanks to wide deployment of PMUs and other DFRs, it is possible to fit the recorded fault data to parameterized dynamic
- y (FIDVR) events of



[Source: LNBL 2010 report]

Challenges

- Loads cannot be separately tested and have to be determined while on-line
- Existing aggregated load models are complicated and highly non-linear
  - include diverse components, such as transformers, power electronics, and motors
  - account for switching events
- Difficult to validate the results as loads are constantly changing
- Our contributions: develop the analytical framework to address the adequacy or necessity of existing dynamic load models

Complexity analysis

- Extremely large number of parameters; 100 + for the WECC CMPLDW
- Some parameters more significantly affect dynamic responses

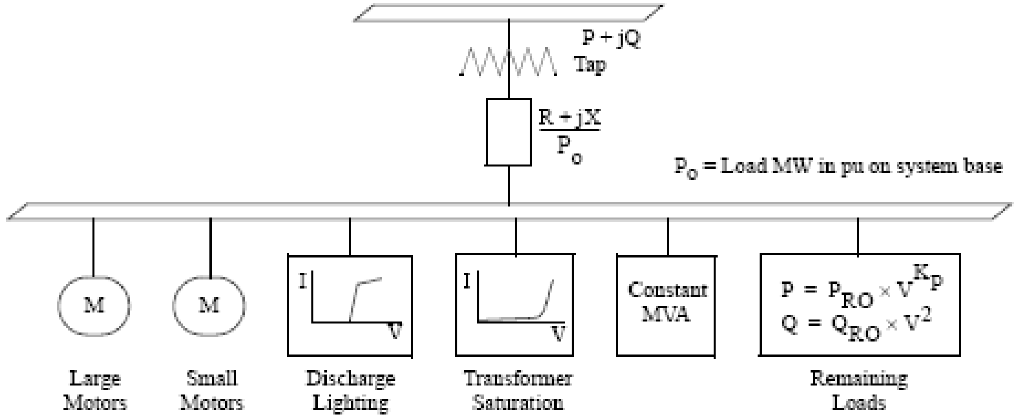
Bss	0	Vd2	0.65	CompPF D	0.97	VrstD	0.9	Ttr2D	5
Rfdr	0.04	Frcel	0.25	LsA	1.8	EtrqA	0	Ftr2A	0.47
Xfdr	0.05	pfs	-0.99	LsB	1.8	EtrqB	2	Ftr2B	0.3
fb	0.75	P1e	2	LsC	1.8	EtrqC	2	Ftr2C	0.3
Xxf	0.08	P1c	0.54546	VstallD	0.6	TrstD	0.4	Vc1offD	0.4
Tfixhs	1	P2e	1	LpA	0.1	Ftr1A	0.2	Vrc1A	0.9
Tfixls	1	P2c	0.45454	LpB	0.16	Ftr1B	0.2	Vrc1B	0.65
ltc	1	Pfrq	0	LpC	0.16	Ftr1C	0.2	Vrc1C	0.65
Tmin	0.9	Q1e	2	RstallD	0.1	FuvrD	0.17	Vc2offD	0.4
Tmax	1.1	Q1c	-0.5	LppA	0.083	Vtr1A	0.75	Trc1A	9999
step	0.00625	Q2e	1	LppB	0.12	Vtr1B	0.5	Trc1B	0.6
Vmin	1	Q2c	1.5	LppC	0.12	Vtr1C	0.5	Trc1C	0.6
Vmax	1.02	Qfrq	-1	XstallD	0.1	Vtr1D	0.65	Vc1onD	0.45
Tdel	30	MtypA	3	TpoA	0.092	Ttr1A	999	Vrc2A	0.639
Ttap	5	MtypB	3	TpoB	0.1	Ttr1B	0.02	Vrc2B	0.85
Rcmp	0	MtypC	3	TpoC	0.1	Ttr1C	0.02	Vrc2C	0.85
Xcmp	0	MtypD	1	TstallD	0.02	Ttr1D	0.02	Vc2onD	0.45
FmA	0.17	LfmA	0.7	TppoA	0.002	Vtr2A	0.5	Trc2A	0.73
FmB	0.1	LFmB	0.8	TppoB	0.0026	Vtr2B	0.7	Trc2B	99999
FmC	0.05	LFmC	0.8	TppoC	0.0026	Vtr2C	0.7	Trc2C	99999
FmD	0.23	LFmD	1	FrstD	0	Vtr2D	0.9	TthD	30
Fel	0.1	RaA	0.04	H A	0.05	Ttr2A	0.02	Th1tD	0.3
Pfel	1	RaB	0.03	H B	1	Ttr2B	0.02	Th2tD	2.05
Vd1	0.75	RaC	0.03	H C	0.1	Ttr2C	0.02	TvD	0.025

Motor Fraction Parameters (%)

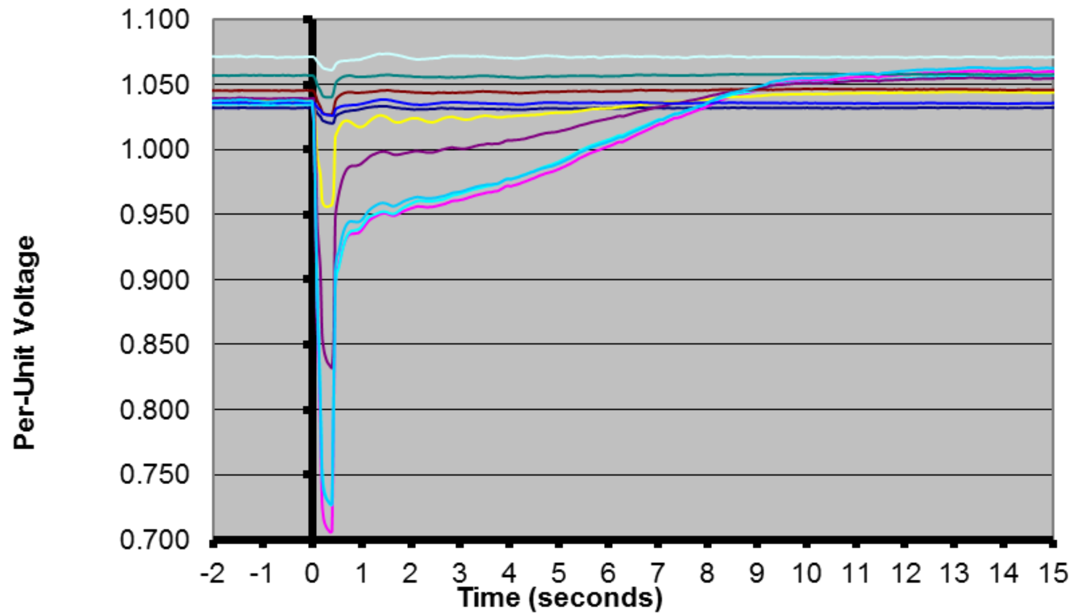
Thermal Protection Parameters

Simpler CLOD model

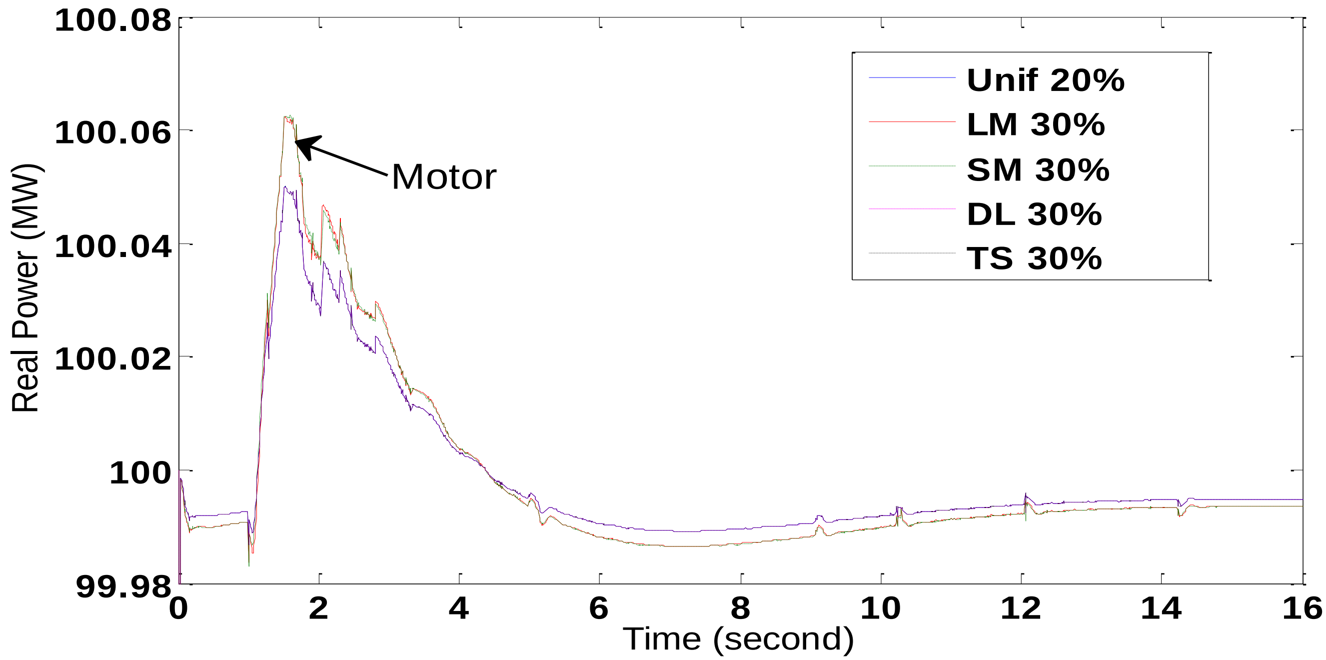
- Parameters: percentage level of
  - Large Motors (LM)
  - Small Motors (SM)
  - Discharge Lighting (DL)
  - Transformer Saturation (TS)
  - Voltage-dependent Loads (VL)



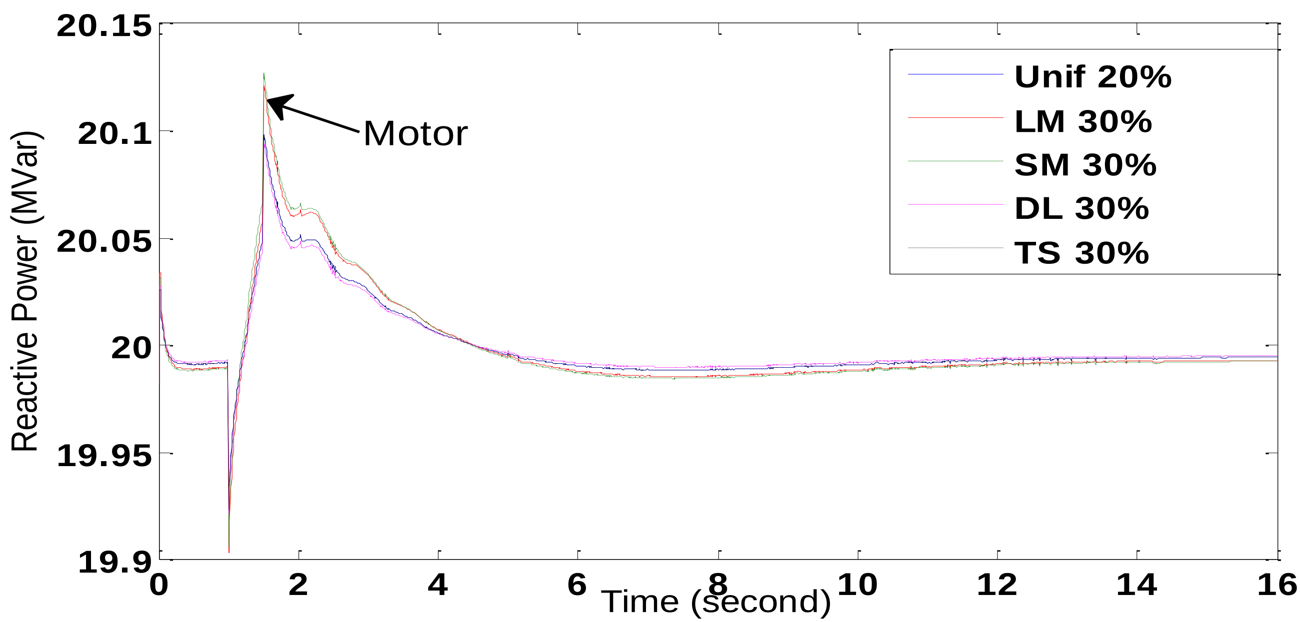
- Use PowerWorld generator playback function to input real voltage data recorded during FIDVR disturbances



CLOD output



100.08
100.06
100.04
100.02
100
99.98
Real Power (MW)
Motor
Unif 20%
LM 30%
SM 30%
DL 30%
TS 30%
0
2
4
6
8
10
12
14
16
Time (second)

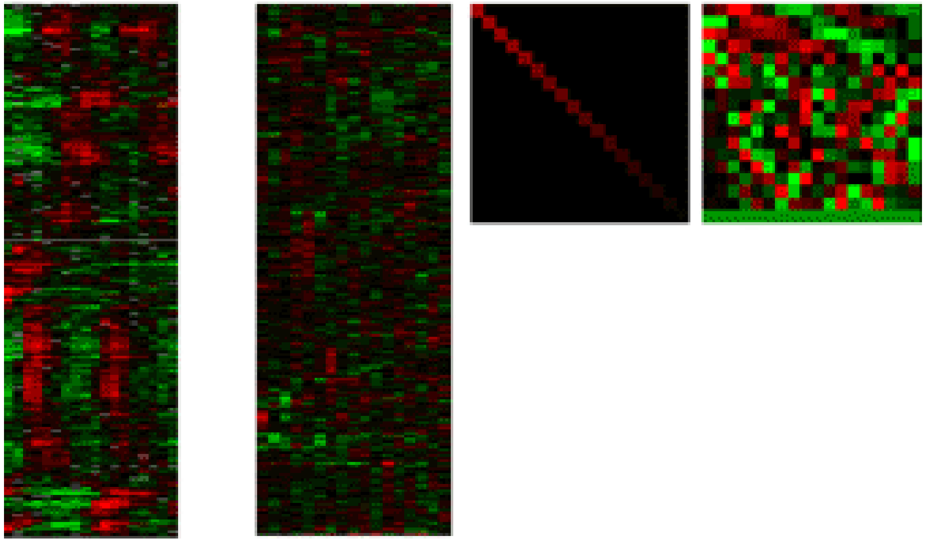


20.15
20.1
20.05
20
19.95
19.9
Reactive Power (MVar)
Motor
Unif 20%
LM 30%
SM 30%
DL 30%
TS 30%
0
2
4
6
8
10
12
14
16
Time (second)

Sparse principal component analysis (S-PCA)

- Without sparsity, PCA is related to SVD matrix decomposition
- Sparsity is advocated to further explore hidden data structure/redundancy for noisy measurements or missing data

$$A = U \cdot W \cdot V^T$$



Preliminary studies

- Both real and reactive power mismatch matrices are almost of rank 1

- The first principal component for Pmat is

  [0.7020, 0.7122, 0.0000, 0.0000]

  – Only changes of LM or SM would affect dynamic response
  – It is the aggregated LM and SM percentages would matter

- The first two principal components for Qmat are

  [0.6212, 0.7627, -0.1800, 0.0000]

  [0.6886,-0.4216, 0.5900, 0.0000]

  – Q response would depend on DL percentage

Conclusions

- Load models are crucial for accurate transient stability studies
- PMUs provide high resolution for measurement-based load models, but it is important to first understand the adequacy or redundancy of models itself
  - Preliminary studies point out parameter identifiability issues
  - (Sparse) PCA method offers the analytical solution to characterize this effect
- Ongoing work
  - Test Sparse PCA for the WECC load model
  - Characterize the dependence on loading conditions
  - Leverage the complexity analysis results to facilitate load estimation in real time