DOE/OE Transmission Reliability Program

FIDVR Load Modeling Tool

Pavel Etingov
Pacific Northwest National Laboratory
pavel.etingov@pnnl.gov
June 10-11, 2015
Washington, DC

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Project team

- PNNL
  - David Chassin
  - Pavel Etingov
  - Yu Zhang
  - Dan James
- Advisors
  - Dmitry Kosterev (BPA)
  - Richard Bravo (SCE)

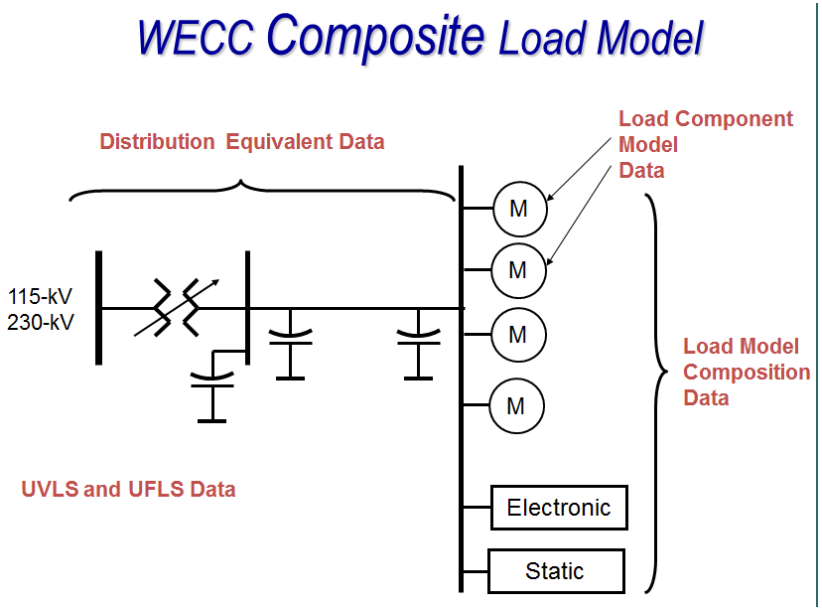
CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Project Objectives

- Utilities have occasionally observed delayed voltage recovery following fault events in regions where a significant portion of the summer peak load is associated with residential air-conditioning.
- This phenomenon, called fault-induced delayed voltage recovery (FIDVR), is associated with motor that are prone to stalling.
- There is concern that as greater a fraction of on-peak load is associated with motors prone to stalling the FIDVR phenomenon could have more significant detrimental impacts and possibly cause generation tripping or even a blackout.
- The purpose of this project is to generalize the load model development and calibration methodology developed for WECC to address the FIDVR phenomenon in planning studies.

Composite Load Model

- In 2000-2001, WECC used interim load model
- In 2005, WECC developed explicit load model
- In 2007, PSLF has the first version of the composite load model



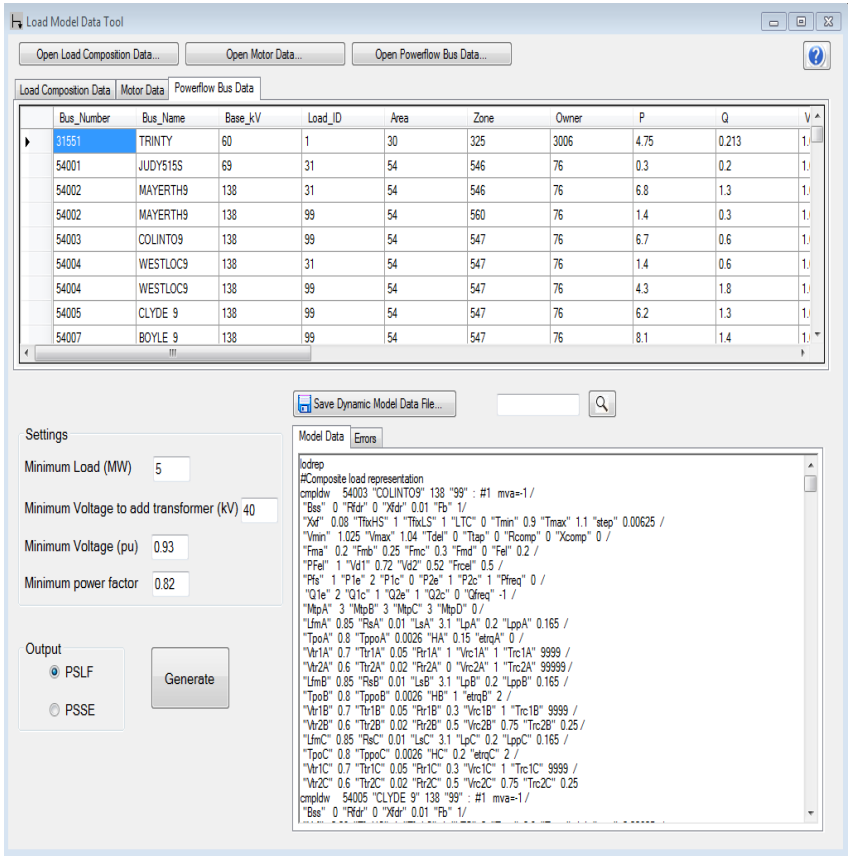
Past major accomplishments

- In 2010, PNNL started the work on load composition model
- Development was funded by DOE through ARRA program
- An Excel tool to create composite load model was developed in 2012.
- Load Model Data Tool to generate composite model data records was developed in 2013

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Load Model Data Tool (LMDT)

- LMDT generates the load composite model data records
- LMDT supports GE PSLF and Siemens PSSE formats
- LMDT 1.0 was released under an open source license in 2013
- LMDT is a stand-alone MS Windows application
- LMDT was developed in collaboration with Bonneville Power Administration (BPA) and WECC Load Modeling Task Force (LMTF)
- Development was funded by DOE ARRA
- LMDT is used by multiple utilities including: WECC, ERCOT, BPA, Dominion, SCE, PG&E, Seattle City Light.

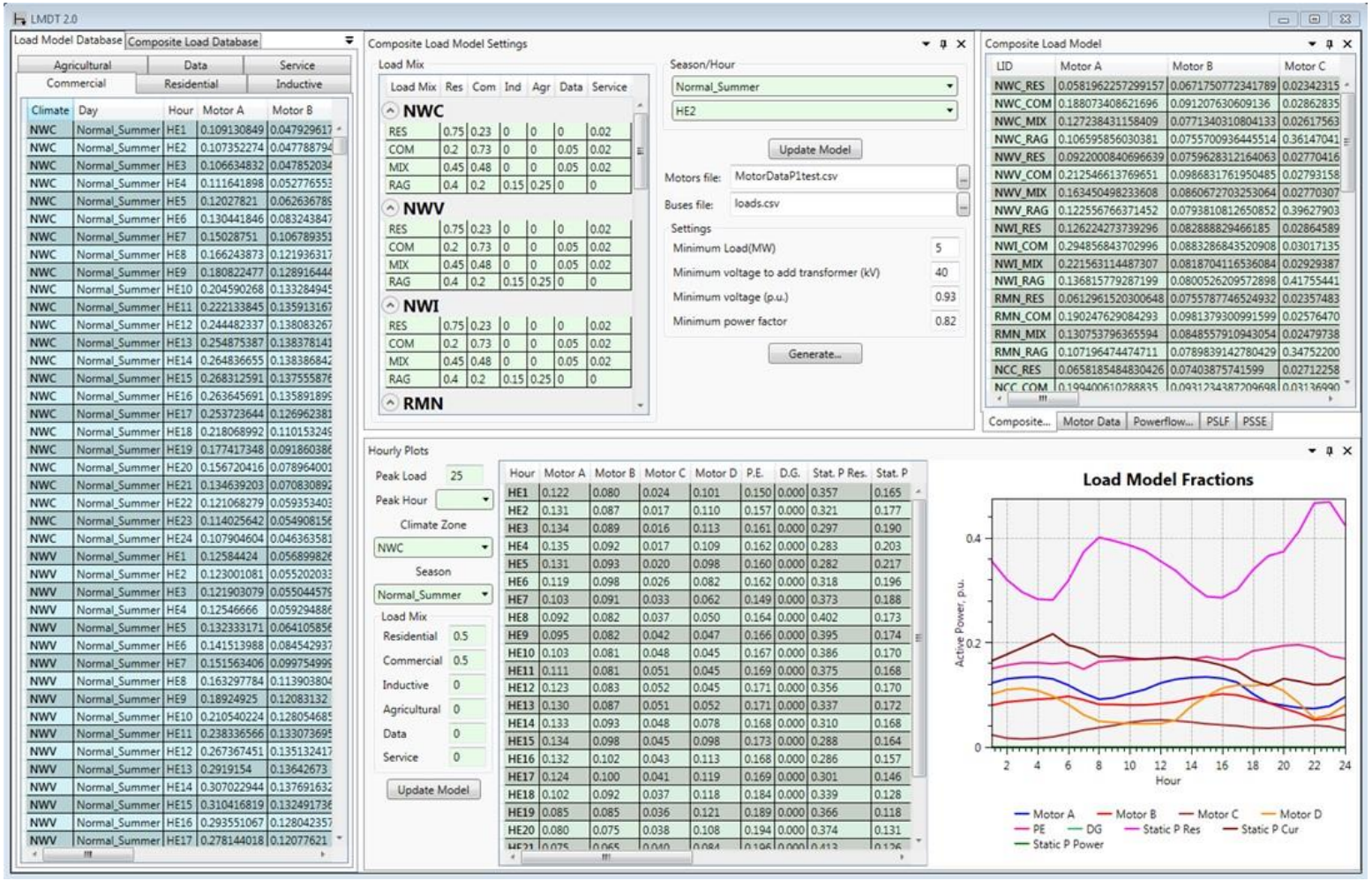


CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Technical Accomplishments FY15

- LMDT is used be WECC to generate CLM records for WECC planning cases.
- Support of PSLF 19 was added to LMDT version 1.1 (this feature was requested by WECC).
- LMDT version 2.0 is under development.
  - Fully redesigned Graphical User Interface (GUI)
  - Advanced functionality
  - Database of load models for different climate zones
  - Generating .dyd and .dyr dynamic records
  - The tool development activity is coordinated with WECC MVWG, WECC LMTF, and BPA

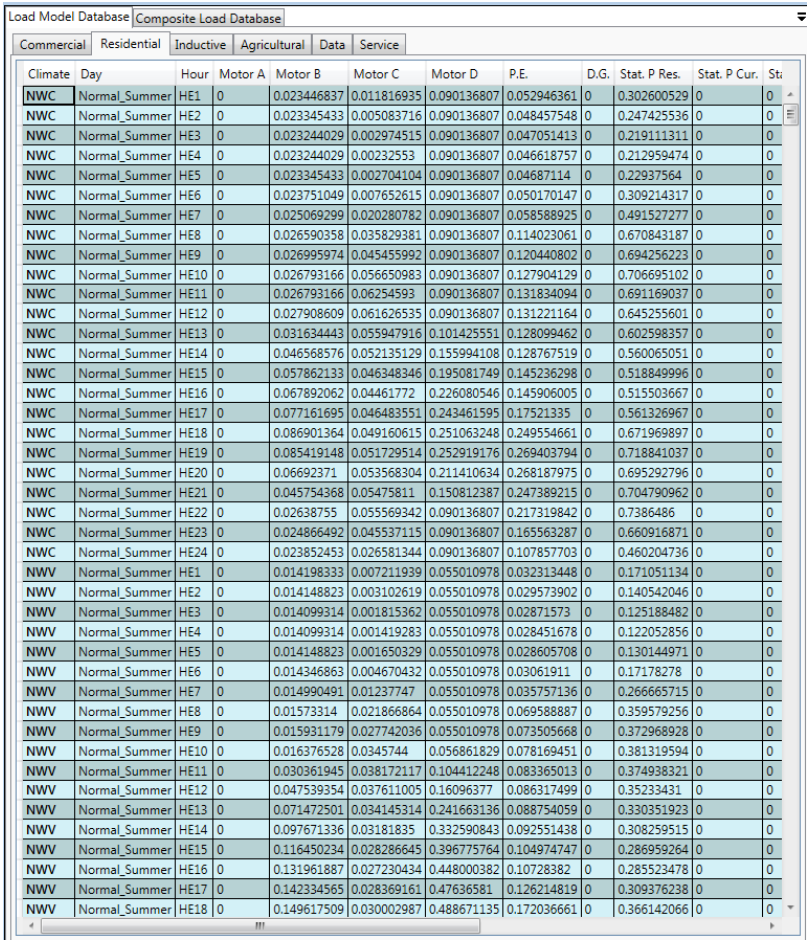
Redesigned Graphical User Interface



CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

LMDT 2.0 Database

- Different load type
  - Commercial
  - Residential
  - Inductive
  - Agricultural
  - Data
  - Service
- Climate zones
- Operating hours
- Seasons



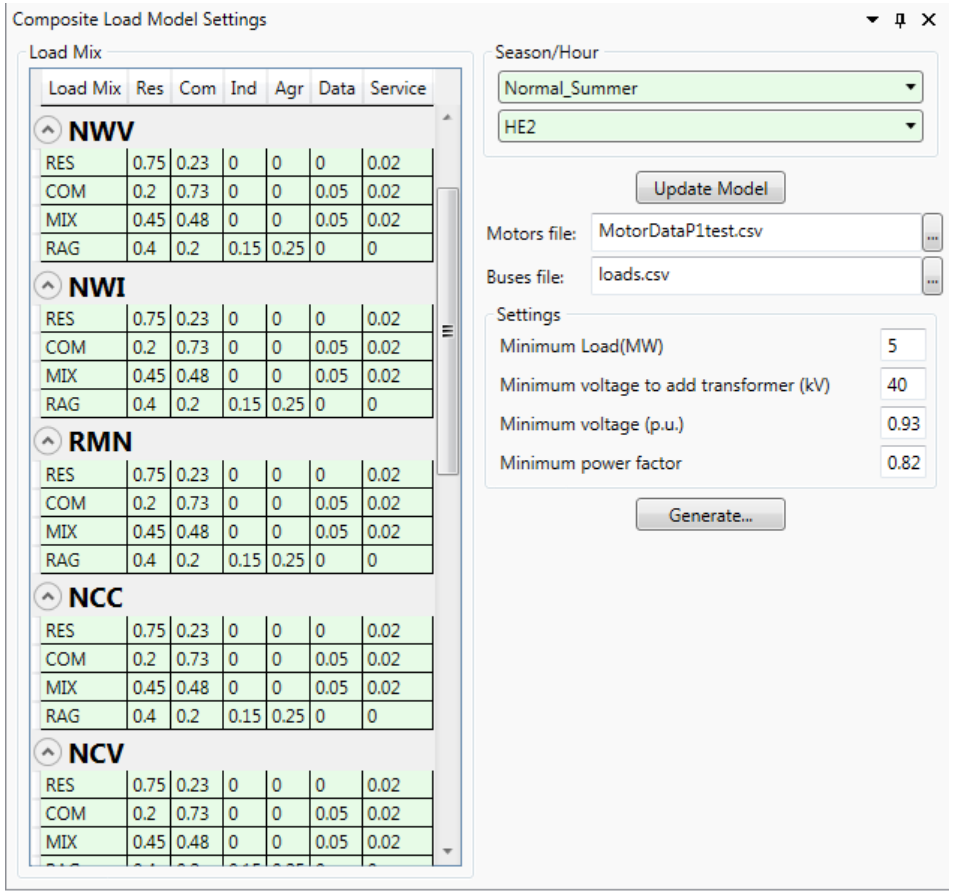
Load Model Database | Composite Load Database

Commercial | Residential | Inductive | Agricultural | Data | Service

Climate	Day	Hour	Motor A	Motor B	Motor C	Motor D	P.E.	D.G.	Stat. P Res.	Stat. P Cur.	St
NWC	Normal_Summer	HE1	0	0.023446837	0.011816935	0.090136807	0.052946361	0	0.302600529	0	0
NWC	Normal_Summer	HE2	0	0.023345433	0.005083716	0.090136807	0.048457548	0	0.247425536	0	0
NWC	Normal_Summer	HE3	0	0.023244029	0.002974515	0.090136807	0.047051413	0	0.219111311	0	0
NWC	Normal_Summer	HE4	0	0.023244029	0.00232553	0.090136807	0.046618757	0	0.212959474	0	0
NWC	Normal_Summer	HE5	0	0.023345433	0.002704104	0.090136807	0.04687114	0	0.22937564	0	0
NWC	Normal_Summer	HE6	0	0.023751049	0.007652615	0.090136807	0.050170147	0	0.309214317	0	0
NWC	Normal_Summer	HE7	0	0.025069299	0.020280782	0.090136807	0.058588925	0	0.491527277	0	0
NWC	Normal_Summer	HE8	0	0.026590358	0.035829381	0.090136807	0.114023061	0	0.670843187	0	0
NWC	Normal_Summer	HE9	0	0.026995974	0.045455992	0.090136807	0.120440802	0	0.694256223	0	0
NWC	Normal_Summer	HE10	0	0.026793166	0.056650983	0.090136807	0.127904129	0	0.706695102	0	0
NWC	Normal_Summer	HE11	0	0.026793166	0.06254593	0.090136807	0.131834094	0	0.691169037	0	0
NWC	Normal_Summer	HE12	0	0.027908609	0.061626535	0.090136807	0.131221164	0	0.645255601	0	0
NWC	Normal_Summer	HE13	0	0.031634443	0.055947916	0.101425551	0.128099462	0	0.602598357	0	0
NWC	Normal_Summer	HE14	0	0.046568576	0.052135129	0.155994108	0.128767519	0	0.560065051	0	0
NWC	Normal_Summer	HE15	0	0.057862133	0.046348346	0.195081749	0.145236298	0	0.518849996	0	0
NWC	Normal_Summer	HE16	0	0.067892062	0.04461772	0.226080546	0.145906005	0	0.515503667	0	0
NWC	Normal_Summer	HE17	0	0.077161695	0.046483551	0.243461595	0.17521335	0	0.561326967	0	0
NWC	Normal_Summer	HE18	0	0.086901364	0.049160615	0.251063248	0.249554661	0	0.671969897	0	0
NWC	Normal_Summer	HE19	0	0.085419148	0.051729514	0.252919176	0.269403794	0	0.718841037	0	0
NWC	Normal_Summer	HE20	0	0.06692371	0.053568304	0.211410634	0.268187975	0	0.695292796	0	0
NWC	Normal_Summer	HE21	0	0.045754368	0.05475811	0.150812387	0.247389215	0	0.704790962	0	0
NWC	Normal_Summer	HE22	0	0.02638755	0.055569342	0.090136807	0.217319842	0	0.7386486	0	0
NWC	Normal_Summer	HE23	0	0.024866492	0.045537115	0.090136807	0.165563287	0	0.660916871	0	0
NWC	Normal_Summer	HE24	0	0.023852453	0.026581344	0.090136807	0.107857703	0	0.460204736	0	0
NWV	Normal_Summer	HE1	0	0.014198333	0.007211939	0.055010978	0.032313448	0	0.171051134	0	0
NWV	Normal_Summer	HE2	0	0.014148823	0.003102619	0.055010978	0.029573902	0	0.140542046	0	0
NWV	Normal_Summer	HE3	0	0.014099314	0.001815362	0.055010978	0.02871573	0	0.125188482	0	0
NWV	Normal_Summer	HE4	0	0.014099314	0.001419283	0.055010978	0.028451678	0	0.122052856	0	0
NWV	Normal_Summer	HE5	0	0.014148823	0.001650329	0.055010978	0.028605708	0	0.130144971	0	0
NWV	Normal_Summer	HE6	0	0.014346863	0.004670432	0.055010978	0.03061911	0	0.17178278	0	0
NWV	Normal_Summer	HE7	0	0.014990491	0.01237747	0.055010978	0.035757136	0	0.266665715	0	0
NWV	Normal_Summer	HE8	0	0.01573314	0.021866864	0.055010978	0.069588887	0	0.359579256	0	0
NWV	Normal_Summer	HE9	0	0.015931179	0.027742036	0.055010978	0.073505668	0	0.372968928	0	0
NWV	Normal_Summer	HE10	0	0.016376528	0.0345744	0.056861829	0.078169451	0	0.381319594	0	0
NWV	Normal_Summer	HE11	0	0.030361945	0.038172117	0.104412248	0.083365013	0	0.374938321	0	0
NWV	Normal_Summer	HE12	0	0.047539354	0.037611005	0.16096377	0.086317499	0	0.35233431	0	0
NWV	Normal_Summer	HE13	0	0.071472501	0.034145314	0.241663136	0.088754059	0	0.330351923	0	0
NWV	Normal_Summer	HE14	0	0.097671336	0.03181835	0.332590843	0.092551438	0	0.308259515	0	0
NWV	Normal_Summer	HE15	0	0.116450234	0.028286645	0.396775764	0.104974747	0	0.286959264	0	0
NWV	Normal_Summer	HE16	0	0.131961887	0.027230434	0.448000382	0.10728382	0	0.285523478	0	0
NWV	Normal_Summer	HE17	0	0.142334565	0.028369161	0.47636581	0.126214819	0	0.309376238	0	0
NWV	Normal_Summer	HE18	0	0.149617509	0.030002987	0.488671135	0.172036661	0	0.366142066	0	0

Composite Load Model Settings

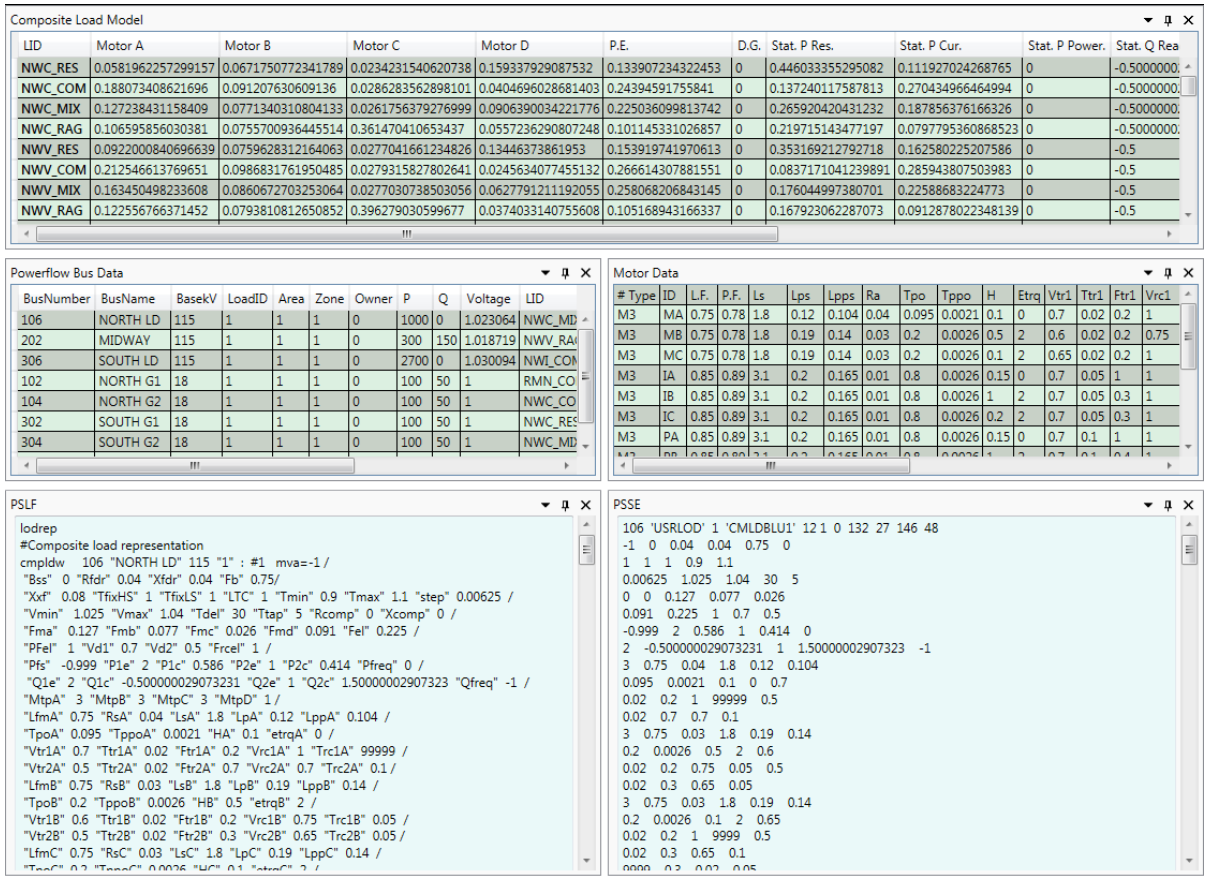
- Load Mix
- Season
- Operating Hour



CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Composite Load Model and Dynamic Records

- Input
  - Composite Load Model
  - Motor Data
  - Power Flow Data
- Output
  - .dyd record
  - .dyr record



Composite Load Model

LID	Motor A	Motor B	Motor C	Motor D	P.E.	D.G.	Stat. P Res.	Stat. P Cur.	Stat. P Power.	Stat. Q Rea
NWC_RES	0.0581962257299157	0.0671750772341789	0.0234231540620738	0.159337929087532	0.133907234322453	0	0.446033355295082	0.111927024268765	0	-0.5000000
NWC_COM	0.188073408621696	0.091207630609136	0.0286283562898101	0.0404696028681403	0.24394591755841	0	0.137240117587813	0.270434966464994	0	-0.5000000
NWC_MIX	0.127238431158409	0.0771340310804133	0.0261756379276999	0.0906390034221776	0.225036099813742	0	0.265920420431232	0.187856376166326	0	-0.5000000
NWC_RAG	0.106595856030381	0.0755700936445514	0.361470410653437	0.0557236290807248	0.101145331026857	0	0.219715143477197	0.0797795360868523	0	-0.5000000
NWV_RES	0.0922000840696639	0.0759628312164063	0.0277041661234826	0.13446373861953	0.153919741970613	0	0.353169212792718	0.162580225207586	0	-0.5
NWV_COM	0.212546613769651	0.0986831761950485	0.0279315827802641	0.0245634077455132	0.266614307881551	0	0.0837171041239891	0.285943807503983	0	-0.5
NWV_MIX	0.163450498233608	0.0860672703253064	0.0277030738503056	0.0627791211192055	0.258068206843145	0	0.176044997380701	0.22588683224773	0	-0.5
NWV_RAG	0.122556766371452	0.0793810812650852	0.396279030599677	0.0374033140755608	0.105168943166337	0	0.167923062287073	0.0912878022348139	0	-0.5

Powerflow Bus Data

BusNumber	BusName	BasekV	LoadID	Area	Zone	Owner	P	Q	Voltage	LID
106	NORTH LD	115	1	1	1	0	1000	0	1.023064	NWC_MD
202	MIDWAY	115	1	1	1	0	300	150	1.018719	NWV_RA
306	SOUTH LD	115	1	1	1	0	2700	0	1.030094	NWI_COM
102	NORTH G1	18	1	1	1	0	100	50	1	RMN_CO
104	NORTH G2	18	1	1	1	0	100	50	1	NWC_CO
302	SOUTH G1	18	1	1	1	0	100	50	1	NWC_RES
304	SOUTH G2	18	1	1	1	0	100	50	1	NWC_MD

Motor Data

# Type	ID	L.F.	P.F.	Ls	Lps	Lpps	Ra	Tpo	Tppo	H	Etrq	Vtr1	Ttr1	Ftr1	Vrc1
M3	MA	0.75	0.78	1.8	0.12	0.104	0.04	0.095	0.0021	0.1	0	0.7	0.02	0.2	1
M3	MB	0.75	0.78	1.8	0.19	0.14	0.03	0.2	0.0026	0.5	2	0.6	0.02	0.2	0.75
M3	MC	0.75	0.78	1.8	0.19	0.14	0.03	0.2	0.0026	0.1	2	0.65	0.02	0.2	1
M3	IA	0.85	0.89	3.1	0.2	0.165	0.01	0.8	0.0026	0.15	0	0.7	0.05	1	1
M3	IB	0.85	0.89	3.1	0.2	0.165	0.01	0.8	0.0026	1	2	0.7	0.05	0.3	1
M3	IC	0.85	0.89	3.1	0.2	0.165	0.01	0.8	0.0026	0.2	2	0.7	0.05	0.3	1
M3	PA	0.85	0.89	3.1	0.2	0.165	0.01	0.8	0.0026	0.15	0	0.7	0.1	1	1

PSLF

```
lodrep
#Composite load representation
cmpldw    106 "NORTH LD" 115 "1" : #1  mva=-1 /
 "Bss"  0 "Rfdr" 0.04 "Xfdr" 0.04 "Fb" 0.75/
 "Xxf"  0.08 "TfixHS" 1 "TfixLS" 1 "LTC" 1 "Tmin" 0.9 "Tmax" 1.1 "step" 0.00625 /
 "Vmin"  1.025 "Vmax" 1.04 "Tdel" 30 "Ttap" 5 "Rcomp" 0 "Xcomp" 0 /
 "Fma"  0.127 "Fmb" 0.077 "Fmc" 0.026 "Fmd" 0.091 "Fel" 0.225 /
 "PFel"  1 "Vd1" 0.7 "Vd2" 0.5 "Frcel" 1 /
 "Pfs"  -0.999 "P1e" 2 "P1c" 0.586 "P2e" 1 "P2c" 0.414 "Pfreq" 0 /
 "Q1e" 2 "Q1c" -0.500000029073231 "Q2e" 1 "Q2c" 1.50000002907323 "Qfreq" -1 /
 "MtpA"  3 "MtpB" 3 "MtpC" 3 "MtpD" 1 /
 "LfmA" 0.75 "RsA" 0.04 "LsA" 1.8 "LpA" 0.12 "LppA" 0.104 /
 "TpoA" 0.095 "TppoA" 0.0021 "HA" 0.1 "etrqA" 0 /
 "Vtr1A" 0.7 "Ttr1A" 0.02 "Ftr1A" 0.2 "Vrc1A" 1 "Trc1A" 99999 /
 "Vtr2A" 0.5 "Ttr2A" 0.02 "Ftr2A" 0.7 "Vrc2A" 0.7 "Trc2A" 0.1 /
 "LfmB" 0.75 "RsB" 0.03 "LsB" 1.8 "LpB" 0.19 "LppB" 0.14 /
 "TpoB" 0.2 "TppoB" 0.0026 "HB" 0.5 "etrqB" 2 /
 "Vtr1B" 0.6 "Ttr1B" 0.02 "Ftr1B" 0.2 "Vrc1B" 0.75 "Trc1B" 0.05 /
 "Vtr2B" 0.5 "Ttr2B" 0.02 "Ftr2B" 0.3 "Vrc2B" 0.65 "Trc2B" 0.05 /
 "LfmC" 0.75 "RsC" 0.03 "LsC" 1.8 "LpC" 0.19 "LppC" 0.14 /
```

PSSE

```
 106 'USRLOD' 1 'CMLDBLU1' 12 1 0 132 27 146 48
 -1   0   0.04   0.04   0.75   0
 1   1   1   0.9   1.1
 0.00625   1.025   1.04   30   5
 0   0   0.127   0.077   0.026
 0.091   0.225   1   0.7   0.5
 -0.999   2   0.586   1   0.414   0
 2   -0.500000029073231   1   1.50000002907323   -1
 3   0.75   0.04   1.8   0.12   0.104
 0.095   0.0021   0.1   0   0.7
 0.02   0.2   1   99999   0.5
 0.02   0.7   0.7   0.1
 3   0.75   0.03   1.8   0.19   0.14
 0.2   0.0026   0.5   2   0.6
 0.02   0.2   0.75   0.05   0.5
 0.02   0.3   0.65   0.05
 3   0.75   0.03   1.8   0.19   0.14
 0.2   0.0026   0.1   2   0.65
 0.02   0.2   1   9999   0.5
 0.02   0.3   0.65   0.1
```

CERTS

CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Hourly Analysis

- Climate Zones
- Seasons
- Load Mix

Hourly Plots

Peak Load 25

Peak Hour

Climate Zone

NWI

Season

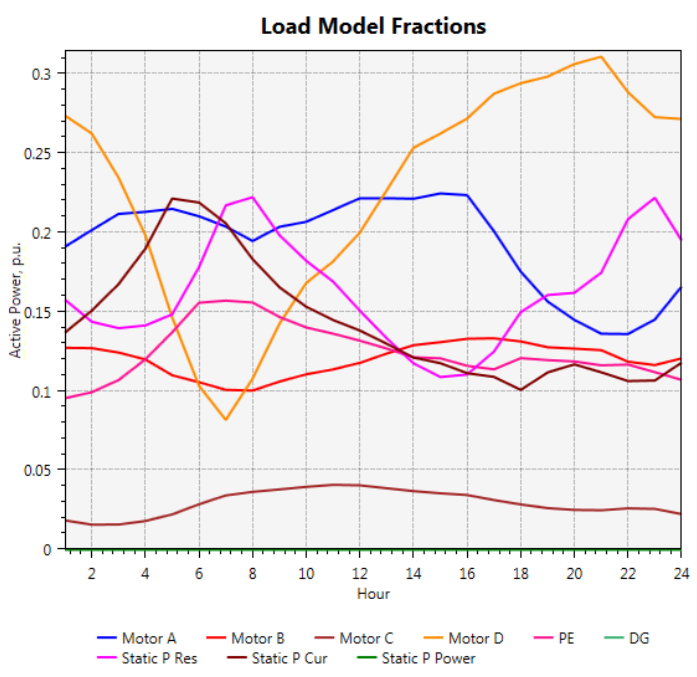
Hot_Summer

Load Mix

Residential	0.5
Commercial	0.5
Inductive	0
Agricultural	0
Data	0
Service	0

Update Model

Hour	Motor A	Motor B	Motor C	Motor D	P.E.	D.G.	Stat. P Res.	Stat. P Cur.	Stat. P Power.	Stat.
HE1	0.191	0.127	0.018	0.274	0.095	0.000	0.158	0.137	0.000	-0.50
HE2	0.201	0.127	0.016	0.262	0.099	0.000	0.144	0.151	0.000	-0.50
HE3	0.212	0.124	0.016	0.235	0.107	0.000	0.140	0.167	0.000	-0.50
HE4	0.213	0.120	0.018	0.198	0.120	0.000	0.141	0.190	0.000	-0.50
HE5	0.215	0.110	0.022	0.146	0.137	0.000	0.148	0.221	0.000	-0.50
HE6	0.210	0.106	0.028	0.103	0.156	0.000	0.178	0.219	0.000	-0.50
HE7	0.204	0.101	0.034	0.082	0.157	0.000	0.217	0.206	0.000	-0.50
HE8	0.195	0.100	0.036	0.108	0.156	0.000	0.222	0.183	0.000	-0.50
HE9	0.204	0.106	0.038	0.142	0.147	0.000	0.198	0.165	0.000	-0.50
HE10	0.207	0.111	0.039	0.168	0.140	0.000	0.182	0.153	0.000	-0.50
HE11	0.214	0.114	0.041	0.182	0.136	0.000	0.169	0.145	0.000	-0.50
HE12	0.222	0.118	0.040	0.200	0.132	0.000	0.151	0.138	0.000	-0.50
HE13	0.222	0.124	0.039	0.227	0.127	0.000	0.133	0.130	0.000	-0.50
HE14	0.221	0.129	0.037	0.253	0.121	0.000	0.117	0.121	0.000	-0.50
HE15	0.225	0.131	0.035	0.262	0.121	0.000	0.109	0.118	0.000	-0.50
HE16	0.224	0.133	0.034	0.272	0.116	0.000	0.110	0.111	0.000	-0.50
HE17	0.201	0.133	0.031	0.287	0.114	0.000	0.125	0.109	0.000	-0.50
HE18	0.175	0.131	0.028	0.294	0.121	0.000	0.150	0.101	0.000	-0.50
HE19	0.156	0.128	0.026	0.298	0.119	0.000	0.160	0.112	0.000	-0.50
HE20	0.145	0.127	0.025	0.306	0.119	0.000	0.162	0.117	0.000	-0.50
HE21	0.136	0.126	0.025	0.311	0.116	0.000	0.175	0.112	0.000	-0.50
HE22	0.136	0.118	0.026	0.288	0.117	0.000	0.208	0.106	0.000	-0.50
HE23	0.145	0.116	0.026	0.273	0.112	0.000	0.222	0.107	0.000	-0.50
HE24	0.166	0.121	0.022	0.272	0.107	0.000	0.195	0.118	0.000	-0.50



Deliverables FY15

- LMDT version 1.1 and tool documentation available at: https://svn.pnl.gov/LoadTool
- Initial prototype version of LMDT 2.0 was provided to a limited number of users for testing

#	Milestone/Deliverable	Target Date
1	*Tool Requirements*	May 2015
2	*Tool specification*	September 2015
3	*Tool prototype*	December 2015
4	*Final tool release*	September 2016

Industry Outreach

The LMDT application has been presented at several industrial events including:

- WECC Modeling and Validation Work Group (MVWG)
- WECC Load Modeling Task Force (LMTF)
- North American Transmission Forum (NATF) Dynamic Load Modeling Working Group
- Webinars for western and eastern interconnection utilities.

Risk factors

- Risk factors are low.
- Feedback and guidance from industrial users are very important for the success of the project.

Future plans

- Expanding analytical capabilities to meet user requirements.
- Model Calibration.
- Industry outreach.