Testing Modular CMLD Representation in GE PSLF (Revised)

WECC MVS Meeting

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Background

- Composite load model CMLD was developed in late 2000s and implemented in all grid simulators used in WECC in early 2010s
- The model structure was fixed with about 160 parameters
- Most of parameters, like motor data, were the same for all models
- The model has no expansion capabilities, if someone wanted to add a new component, e.g. Electric Vehicle Charger model, VFD model or single phase AC phasor model
- WECC has discussed the need for “modular” CMLD implementation, which will enable more efficient data management and capabilities to expand the model components
- PowerWorld and GE PSLF implemented “modular” CMLD in the their simulation packages
- This study aims to benchmark conventional and modular CMLD models in WECC-wide studies

Study Description

- Operational summer peak case
- Central Oregon area is high desert with summer peak temperatures in excess of 100F
- Rapid population and load growth
- Simulated 3-phase faults applied at EHV lines
  - Remote substations
  - Close substation

Study Description

- CMLD implementation
  - Baseline: Zone level models currently used in WECC
  - Modular CMLD representation, using same data
  - Modular CMLD representation, inverse-time stalling implemented for AC motor performance model
  - Modular CMLD representation, dynamic phasor model is used to represent single-phase motors

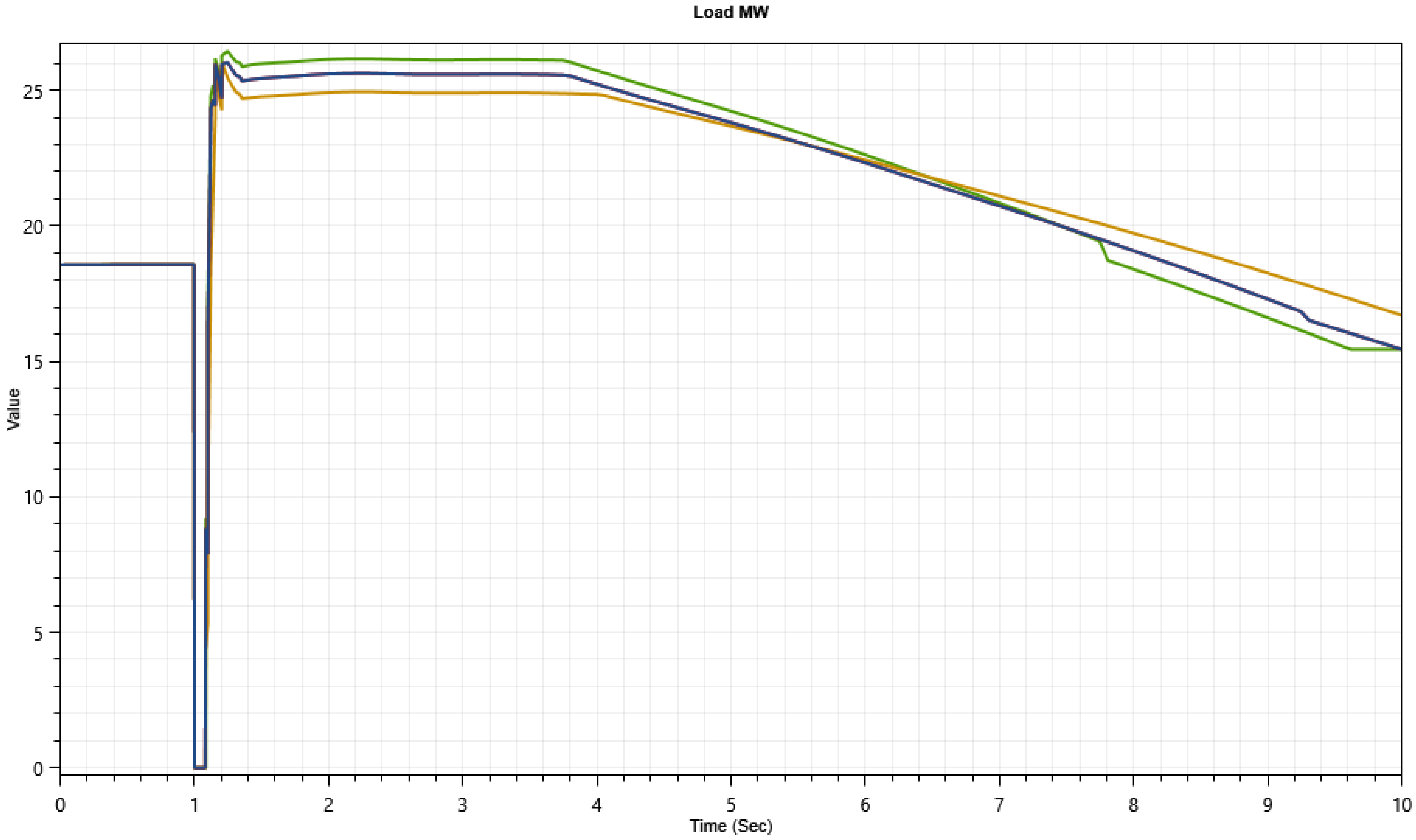
- Simulated

  (A) 3-phase fault applied at adjacent 115-kV line, normal clearing 5-cycle near end and 6 cycle far end

  (B) 3-phase fault applied at one of EHV lines in the area, normal clearing 3-cycle near end and 4-cycle far end

115-kV SubGrid Fault

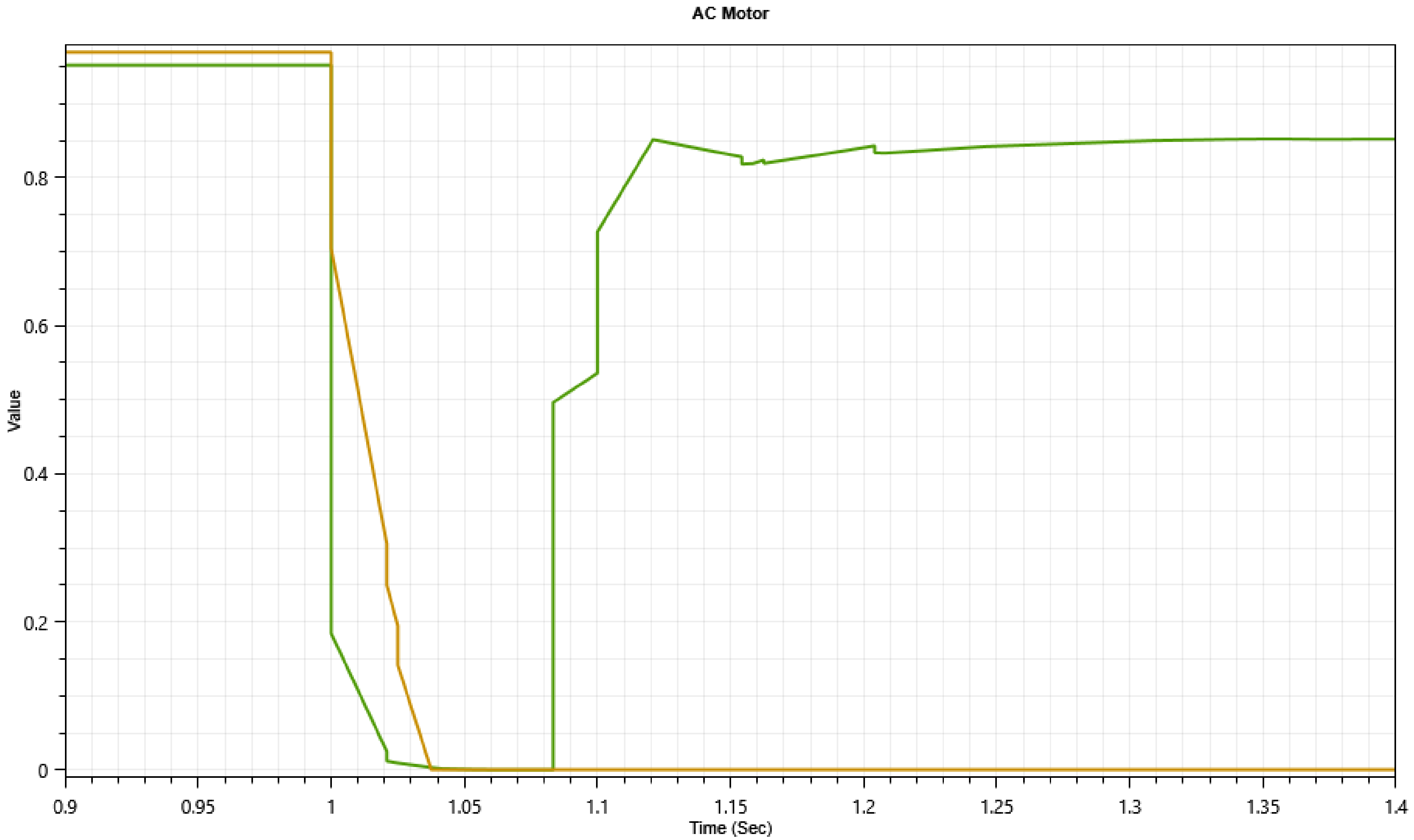
Local Load MWs



Green (existing model)
Red (modular model)
Blue (modular model with time-dependent stalling)
Orange (modular model with phasor AC motor model)

All show similar FIDVR signature

AC Motor Speed – Phasor Model

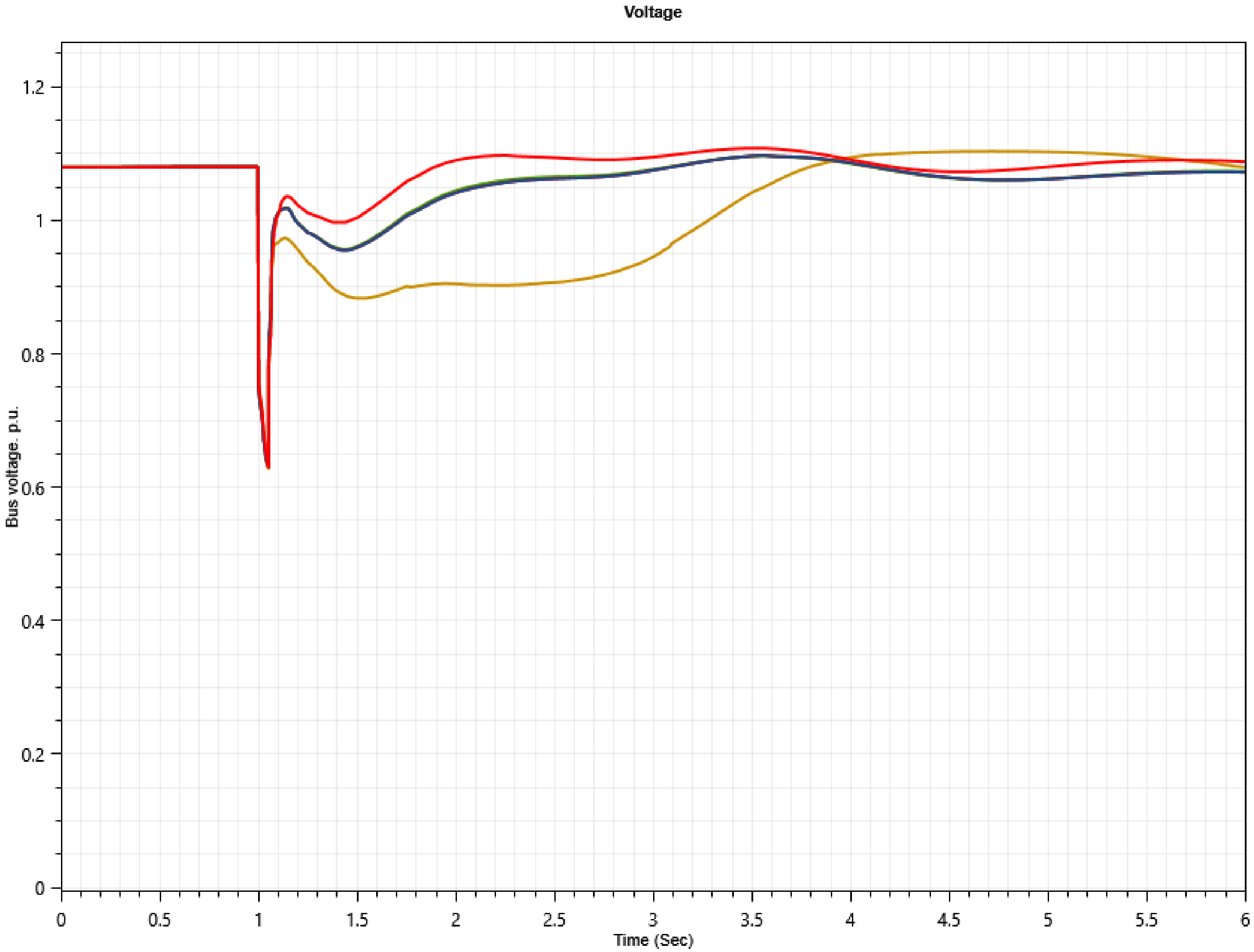


AC Motor Model Voltage

AC Motor Model stalls fast and remains stalled

Main Grid EHV Fault

Main Grid Voltages



The following curves overlay nearly perfectly:

Green (existing model)

Blue (modular model)

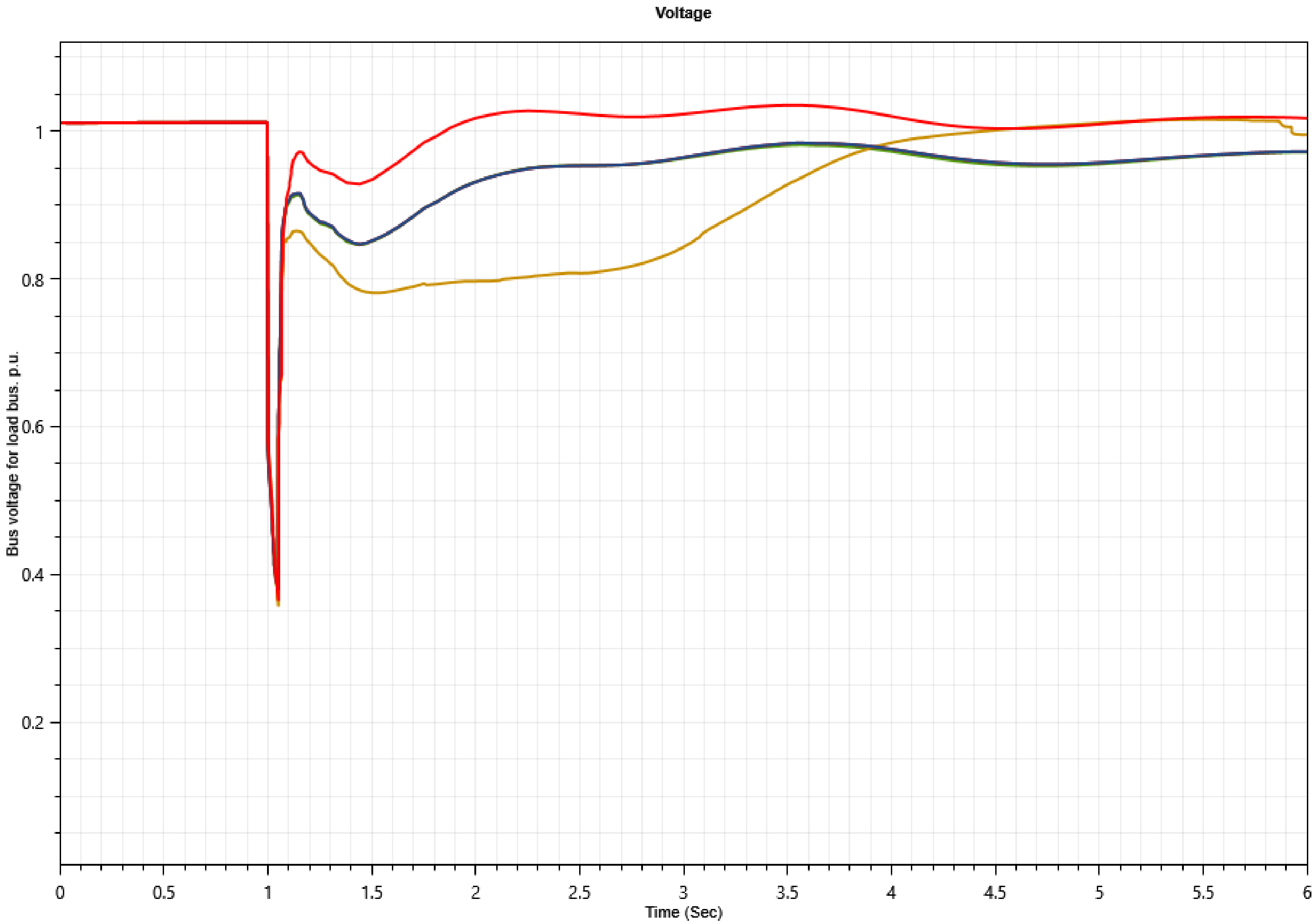
AC motors stall

Orange (modular model with phasor AC motor model, D=1)

AC Motors reaccelerate

Red (modular model with phasor AC motor model, D=2)

Local Load Voltages

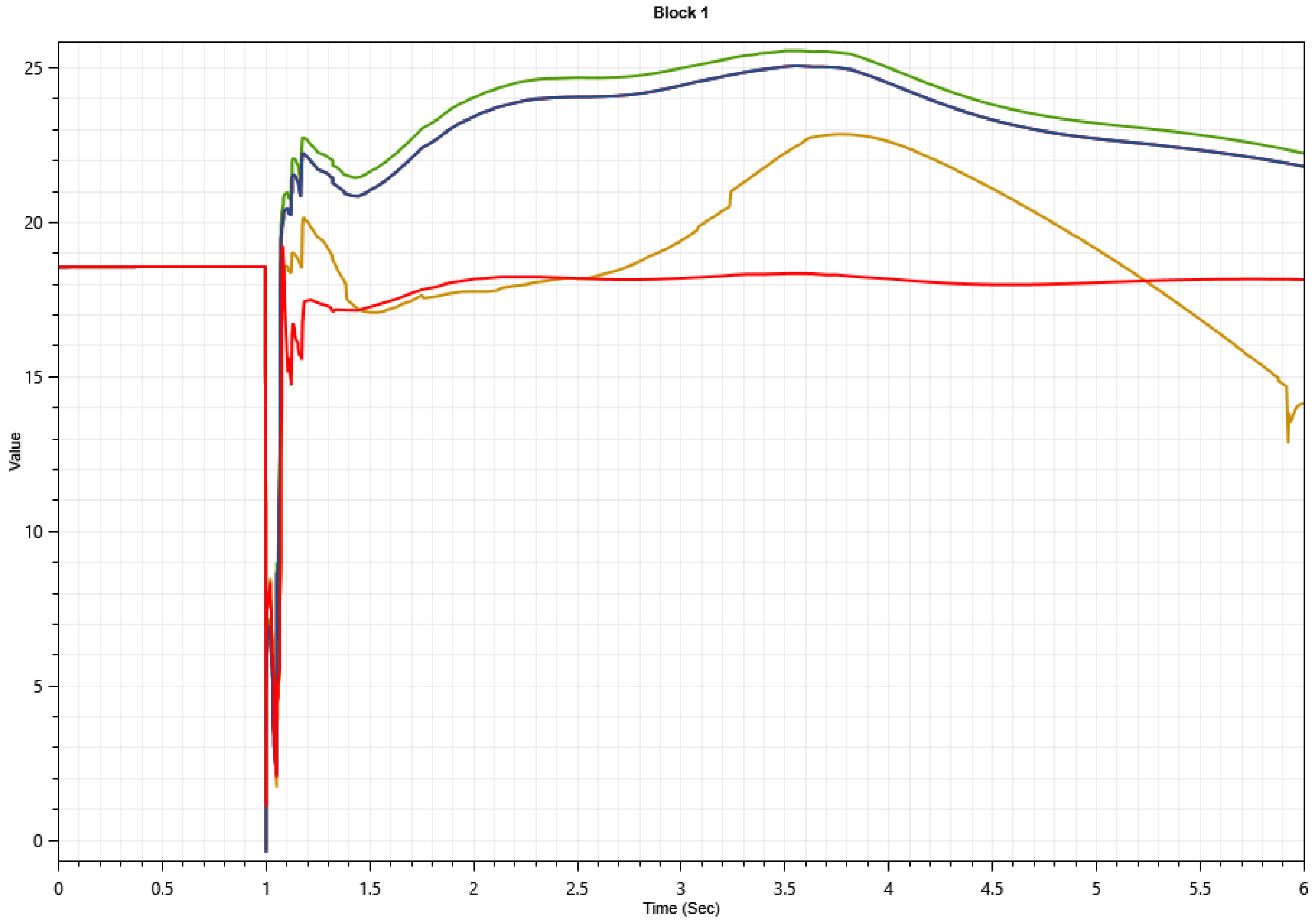


The following curves overlay nearly perfectly:
Green (existing model)
Blue (modular model)

AC motors stall
Orange (modular model with phasor AC motor model, D=1)

AC Motors reaccelerate
Red (modular model with phasor AC motor model, D=2)

Local Load MWs

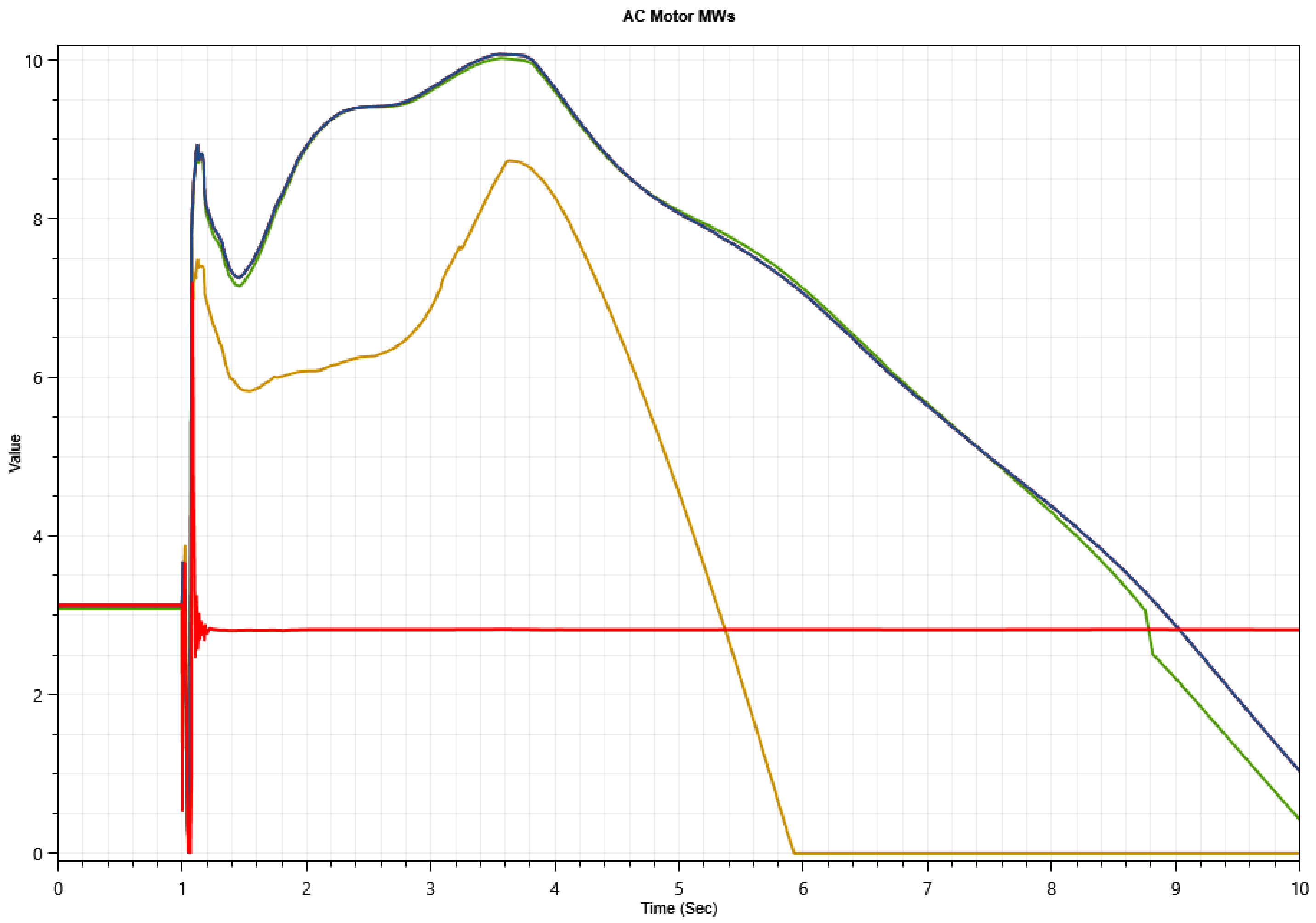


The following curves overlay nearly perfectly:
Green (existing model)
Blue (modular model)

AC motors stall
Orange (modular model with phasor AC motor model, D=1)

AC Motors reaccelerate
Red (modular model with phasor AC motor model, D=2)

AC Motor Model MWs



The following curves overlay nearly perfectly:

Green (existing model)

Blue (modular model)

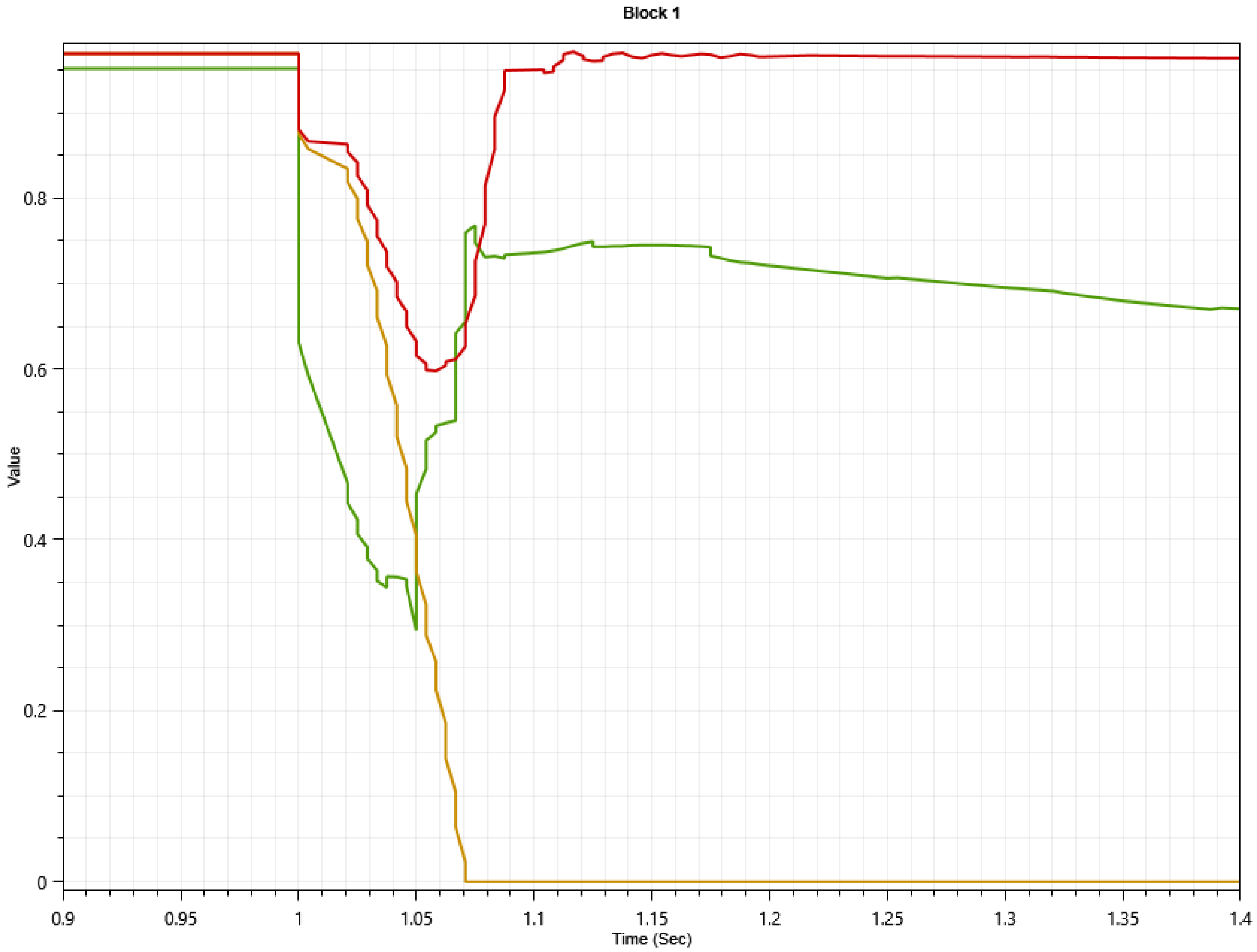
AC motors stall

Orange (modular model with phasor AC motor model, D=1)

AC Motors reaccelerate

Red (modular model with phasor AC motor model, D=2)

AC Motor Speed – Phasor Model

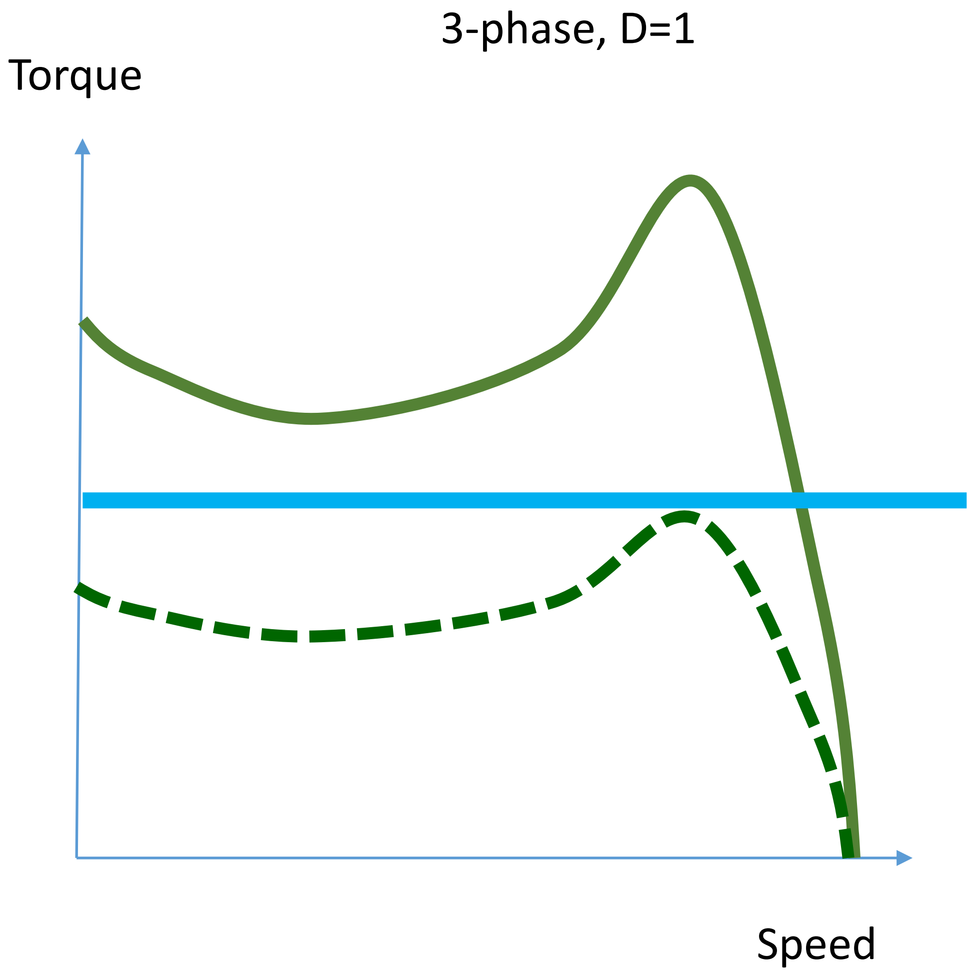


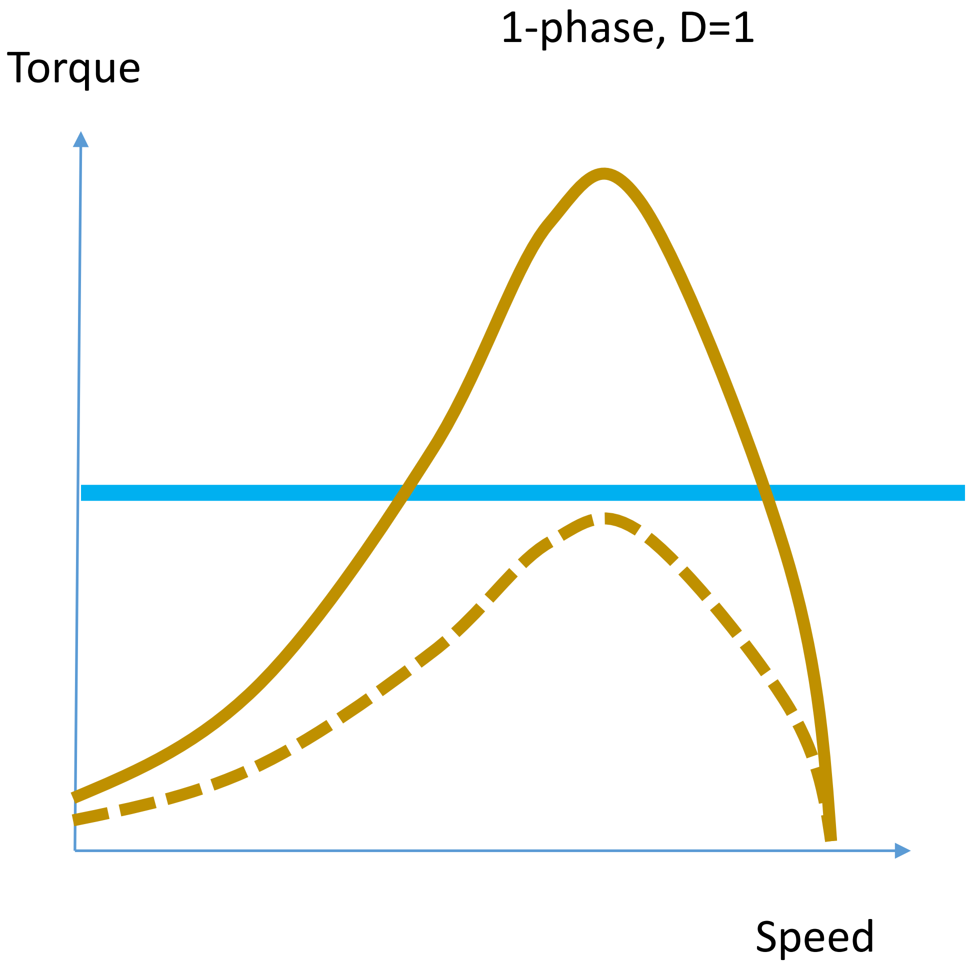
AC Motor Model Voltage

AC motors stall Orange (modular model with phasor AC motor model, D=1)

AC Motors reaccelerate Red (modular model with phasor AC motor model, D=2)

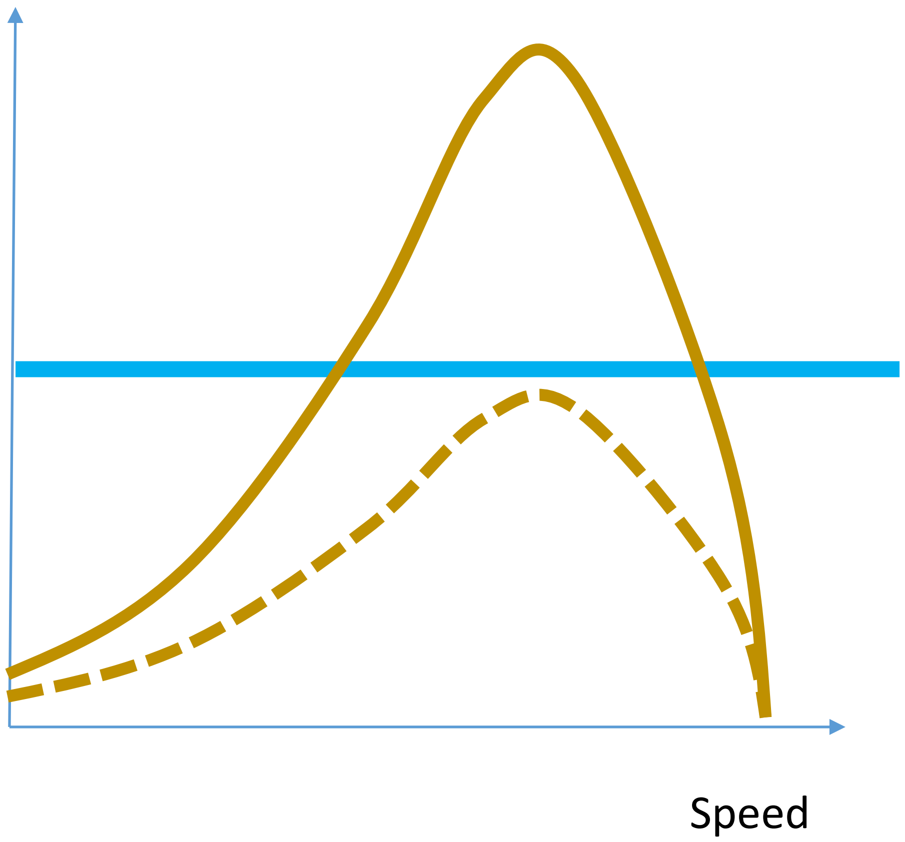
Motor Torque-Speed Curves



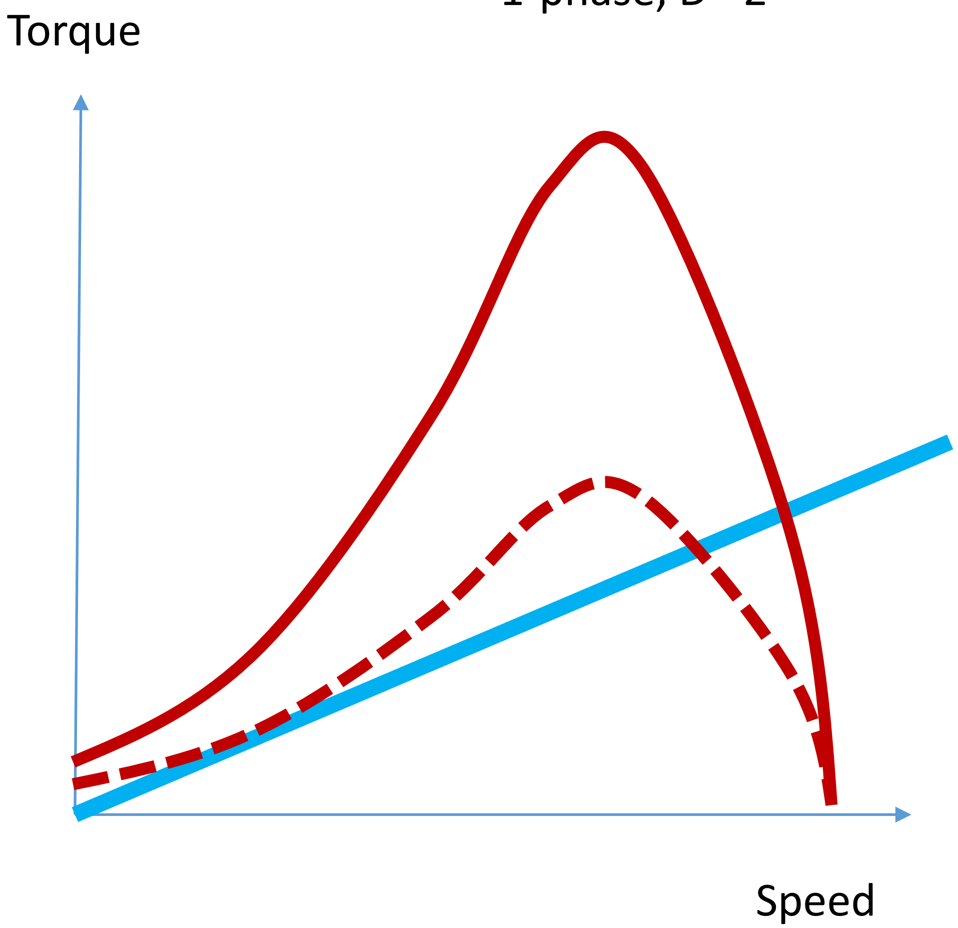


Motor Torque-Speed Curves

1-phase, D = 1



1-phase, D= 2



Study Conclusions

- Modular CMLD representation seems to work in GE PSLF regional studies

- Modular CMLD representation allows replacement of LD1PAC performance model with MOT1PH dynamic phasor motor model
  - For remote faults, dynamic phasor model MOT1PH shows motors reaccelerate after fault clearing, while performance model LD1PAC shows motor stalling for same fault
  - There are performance difference for remote faults
  - Assumptions on motor-driven load are critical
  - **MOT1PH with D=1 model runs a lot slower**
  - MOT1PH is not ready for WECC-wide studies

Study Recommendations

- Modular representation
  - Ensure all grid simulators have modular CMLD representation available
  - Perform comprehensive benchmarking of modular CMLD implementation
    - Small test system
    - Large scale WECC-wide studies
- Tools
  - Update NERC LMDT tools to write modular CMLD
- Dynamic phasor model
  - Ensure all grid simulators have dynamic phasor model implemented and integrated with modular CMLD
  - Benchmark dynamic phasor models
  - Validate dynamic phasor model parameters

Model Data

Original CMLD Model

```
_cmpldw  -17  "NWV_MIX"  0 : #9  mva=-1.000000 /
  "Pmin"  5.000 "PQmin"  1.4327 "Vmin"  0.9300 "kVthresh"  40.000 /
  "Bss"  0.00 "Rfdr" 0.040 "Xfdr" 0.040 "Fb" 0.750 /
  "Xxf" 0.080 "TfixHS" 1.000 "TfixLS" 1.000 "LTC" 1  "Tmin" 0.900 "Tmax" 1.100 "step" 0.00625 /
  "Vmin" 1.025 "Vmax" 1.040 "Tdel" 30.00 "Ttap" 5.00 "Rcomp" 0.000 "Xcomp" 0.000 /
  "Fma" 0.145 "Fmb" 0.148 "Fmc" 0.052 "Fmd" 0.173 "Fel" 0.159 /
  "PFel" 1.000 "Vd1" 0.700 "Vd2" 0.500 "Frcel" 1.000 /
  "Pfs" -0.998 "P1e" 2.0 "P1c" 0.553 "P2e" 1.0 "P2c" 0.447 "Pfreq" 0.000 /
        "Q1e" 2.0 "Q1c" -0.500 "Q2e" 1.0 "Q2c" 1.500 "Qfreq" -1.000 /
  "MtpA" 3 "MtpB" 3 "MtpC" 3 "MtpD" 1 /
  "Lfm" 0.750 "Rs" 0.040 "Ls" 1.800 "Lp" 0.120 "LppA" 0.104 /
  "Tpo" 0.095 "Tppo" 0.0021 "H" 0.100 "etrq" 0.000 /
  "Vtr1" 0.700 "Ttr1" 0.100 "Ftr1" 0.200 "Vrc1" 1.000 "Trc1" 99999.000 /
 "Vtr2" 0.500 "Ttr2" 0.020 "Ftr2" 0.700 "Vrc2" 0.700 "Trc2" 0.100 /
  "Lfm" 0.750 "Rs" 0.030 "Ls" 1.800 "Lp" 0.190 "LppA" 0.140 /
  "Tpo" 0.200 "Tppo" 0.0026 "H" 0.500 "etrq" 2.000 /
  "Vtr1" 0.600 "Ttr1" 0.020 "Ftr1" 0.200 "Vrc1" 0.750 "Trc1" 0.050 /
  "Vtr2" 0.500 "Ttr2" 0.020 "Ftr2" 0.300 "Vrc2" 0.650 "Trc2" 0.050 /
  "Lfm" 0.750 "Rs" 0.030 "Ls" 1.800 "Lp" 0.190 "LppA" 0.140 /
  "Tpo" 0.200 "Tppo" 0.0026 "H" 0.100 "etrq" 2.000 /
  "Vtr1" 0.650 "Ttr1" 0.020 "Ftr1" 0.200 "Vrc1" 1.000 "Trc1" 9999.000 /
  "Vtr2" 0.500 "Ttr2" 0.020 "Ftr2" 0.300 "Vrc2" 0.650 "Trc2" 0.100 /
  "LfmD" 1.000 "CompPF" 0.980 /
  "Vstall" 0.450 "Rstall" 0.100 "Xstall" 0.100 "Tstall" 0.032 "Frst" 0.200 "Vrst" 0.950 "Trst" 0.300 /
  "fuvr" 0.100 "vtr1" 0.600 "ttr1" 0.020 "vtr2" 0.000 "ttr2" 9999.000 /
  "Vc1off" 0.500 "Vc2off" 0.400 "Vc1on" 0.600 "Vc2on" 0.500 /
  "Tth" 15.00 "Th1t" 0.700 "Th2t" 1.900 "tv" 0.025 /
  "DGtype" 2 "dgdatno" -110 "dgmbase" -0.9
```

Modular CMLD Model

```
_cmpldw2   -17   "NWV_MIX"   0 : #9  mva=-1.000000 /
 "Pmin"    5.0000 "PQmin"    1.4327 "Vmin"    0.9300 "kVthresh"   40.0000 /
      cmp_dist   -10  /
      cmp_stat   -100199   -1.0000  /
      cmp_elec   -100299    0.159  /
      cmp_mot3   -100499    0.145  /
      cmp_mot3   -100699    0.148  /
      cmp_mot3   -100899    0.052  /
      cmp_1pac   -100988    0.173  /
      cmp_der_a     -110    1.0000   "dgmbase"   -0.9000
```

```
_cmp_mot3       -100499  :  "lfm" 0.750000 "Ra" 0.040000 "Ls"   1.8000 "Lp" 0.120000 "Lpp" 0.104000 "Tpo" 0.095000 "Tppo" 0.002100 "H" 0.100000 "Etrq" 0.0 "Vtr1" 0.700000 /
 "Ttr1" 0.100000 "Ftr1" 0.200000 "Vrc1" 1.000000 "Trc1" 99999.00 "Vtr2" 0.500000 "Ttr2" 0.020000 "Ftr2" 0.700000 "Vrc2" 0.700000 "Trc2" 0.100000
_cmp_mot3       -100699  :  "lfm" 0.750000 "Ra" 0.030000 "Ls"   1.8000 "Lp" 0.190000 "Lpp" 0.140000 "Tpo" 0.200000 "Tppo" 0.002600 "H" 0.500000 "Etrq"   2.0000 "Vtr1" 0.600000 /
 "Ttr1" 0.020000 "Ftr1" 0.200000 "Vrc1" 0.750000 "Trc1" 0.050000 "Vtr2" 0.500000 "Ttr2" 0.020000 "Ftr2" 0.300000 "Vrc2" 0.650000 "Trc2" 0.050000
_cmp_mot3       -100899  :  "lfm" 0.750000 "Ra" 0.030000 "Ls"   1.8000 "Lp" 0.190000 "Lpp" 0.140000 "Tpo" 0.200000 "Tppo" 0.002600 "H" 0.100000 "Etrq"   2.0000 "Vtr1" 0.650000 /
 "Ttr1" 0.020000 "Ftr1" 0.200000 "Vrc1" 1.000000 "Trc1"  9999.00 "Vtr2" 0.500000 "Ttr2" 0.020000 "Ftr2" 0.300000 "Vrc2" 0.650000 "Trc2" 0.100000
_cmp_1pac       -100988  :  "lfm" 1.000000 "CompPF" 0.980000 "Vstall" 0.450000 "Rstall" 0.100000 "Xstall" 0.100000 "Tstall" 0.032000 "Frst" 0.200000 "Vrst" 0.950000 "Trst" 0.300000 "fuvr" 0.100000 /
 "vtr1" 0.600000 "ttr1" 0.020000 "vtr2" 0.0 "ttr2"  9999.00 "Vc1off" 0.500000 "Vc2off" 0.400000 "Vc1on" 0.600000 "Vc2on" 0.500000 "Tth"  15.0000 "Th1t" 0.700000 /
 "Th2t"   1.9000 "Tv" 0.025000
_cmp_elec       -100299  :  "pfel" 1.000000 "vd1" 0.700000 "vd2" 0.500000 "frcel" 1.000000
_cmp_stat       -100199  :  "pfs" -1.000000 "p1e"   2.0000 "p1c" 0.838000 "p2e" 1.000000 "p2c" 0.162000 "pfrq" 0.0 "q1e"   2.0000 "q1c" -0.500000 "q2e" 1.000000 "q2c"   1.5000 /
 "qfrq" -1.000000
_cmp_dist       -10      :  "bss" 0.0 "rfdr" 0.040000 "xfdr" 0.040000 "xxf" 0.080000 "tfixhs" 1.000000 "tfixls" 1.000000 "ltc" 1.000000 "tmin" 0.900000 "tmax"   1.1000 "step" 0.006250 /
 "vmin" 0.930000 "vmax"   1.0400 "tdel"  30.0000 "ttap"   5.0000 "rcmp" 0.0 "xcmp" 0.0 "s1" 0.0 "s12" 0.0
```

Modular CMLD with Dynamic Motor Model

_cmpldw2 -17 "NWV_MIX" 0 : #9 mva=-1.000000 /

"Pmin" 5.0000 "PQmin" 1.4327 "Vmin" 0.9300 "kVthresh" 40.0000 /

cmp_dist -10 /

cmp_stat -100199 -1.0000 /

cmp_elec -100299 0.159 /

cmp_mot3 -100499 0.145 /

cmp_mot3 -100699 0.148 /

cmp_mot3 -100899 0.052 /

cmp_mo1ph -601 0.173 /

cmp_der_a -110 1.0000 "dgmbase" -0.9000

_cmp_mo1ph -601 : /

"pul" 1.0 "Rds" 0.0365 "Rqs" 0.0729 "Xm" 2.28 "Xcap" -2.78 "Xpd" 0.103 "Xpq" 0.149 /

"Xr" 2.33 "Tp0" 0.12 "H" 0.04 "D" 1.0 /

"Asat" 5.6 "Bsat" 0.72 "ratio" 1.22 "ndelt" 20.0 "wdelt" 2.0/

"Vc1off" 0.5 "Vc2off" 0.4 "Vc1on" 0.6 "Vc2on" 0.5 "Tth" 15.0 "Th1t" 0.30 "Th2t" 0.81 /

"fuvr" 0.1 "uvtr1" 0.6 "ttrr1" 0.02 "uvtr2" 0.0 "ttr2" 9999.0 "tv" 0.025

_cmp_mot3 -100499 : "lfm" 0.750000 "Ra" 0.040000 "Ls" 1.8000 "Lp" 0.120000 "Lpp" 0.104000 "Tpo" 0.095000 "Tppo" 0.002100 "H" 0.100000 "Etrq" 0.0 "Vtr1" 0.700000 /

"Ttr1" 0.100000 "Ftr1" 0.200000 "Vrc1" 1.000000 "Trc1" 99999.00 "Vtr2" 0.500000 "Ttr2" 0.020000 "Ftr2" 0.700000 "Vrc2" 0.700000 "Trc2" 0.100000

_cmp_mot3 -100699 : "lfm" 0.750000 "Ra" 0.030000 "Ls" 1.8000 "Lp" 0.190000 "Lpp" 0.140000 "Tpo" 0.200000 "Tppo" 0.002600 "H" 0.500000 "Etrq" 2.0000 "Vtr1" 0.600000 /

"Ttr1" 0.020000 "Ftr1" 0.200000 "Vrc1" 0.750000 "Trc1" 0.050000 "Vtr2" 0.500000 "Ttr2" 0.020000 "Ftr2" 0.300000 "Vrc2" 0.650000 "Trc2" 0.050000

_cmp_mot3 -100899 : "lfm" 0.750000 "Ra" 0.030000 "Ls" 1.8000 "Lp" 0.190000 "Lpp" 0.140000 "Tpo" 0.200000 "Tppo" 0.002600 "H" 0.100000 "Etrq" 2.0000 "Vtr1" 0.650000 /

"Ttr1" 0.020000 "Ftr1" 0.200000 "Vrc1" 1.000000 "Trc1" 9999.00 "Vtr2" 0.500000 "Ttr2" 0.020000 "Ftr2" 0.300000 "Vrc2" 0.650000 "Trc2" 0.100000

_cmp_1pac -100988 : "lfm" 1.000000 "CompPF" 0.980000 "Vstall" 0.450000 "Rstall" 0.100000 "Xstall" 0.100000 "Tstall" 0.032000 "Frst" 0.200000 "Vrst" 0.950000 "Trst" 0.300000 "fuvr" 0.100000 /

"vtr1" 0.600000 "ttr1" 0.020000 "vtr2" 0.0 "ttr2" 9999.00 "Vc1off" 0.500000 "Vc2off" 0.400000 "Vc1on" 0.600000 "Vc2on" 0.500000 "Tth" 15.0000 "Th1t" 0.700000 /

"Th2t" 1.9000 "Tv" 0.025000

_cmp_elec -100299 : "pfel" 1.000000 "vd1" 0.700000 "vd2" 0.500000 "frcel" 1.000000

_cmp_stat -100199 : "pfs" -1.000000 "p1e" 2.0000 "p1c" 0.838000 "p2e" 1.000000 "p2c" 0.162000 "pfrq" 0.0 "q1e" 2.0000 "q1c" -0.500000 "q2e" 1.000000 "q2c" 1.5000 /

"qfrq" -1.000000

_cmp_dist -10 : "bss" 0.0 "rfdr" 0.040000 "xfdr" 0.040000 "xxf" 0.080000 "tfixhs" 1.000000 "tfixls" 1.000000 "ltc" 1.000000 "tmin" 0.900000 "tmax" 1.1000 "step" 0.006250 /

"vmin" 0.930000 "vmax" 1.0400 "tdel" 30.0000 "ttap" 5.0000 "rcmp" 0.0 "xcmp" 0.0 "s1" 0.0 "s12" 0.0

Dynamic Motor Data

- Damping coefficient of D=1 is needed to represent constant torque load

$$T_m = P_{mech\ init} * \omega_r^{D-1}$$

- Thermal relay model data needs to be modified
  - Performance model calculates heat as I2R, where R is the resistance of stalled motor and includes both stator and rotor resistance
  - Phasor model calculates heat as I2R too, but R is the stator resistance only. Stator resistance is 43% of the combined stator plus rotor resistance, therefore “Th1T” and “Th2t” are scaled by 43% in dynamic phasor model