WECC

WECC Composite Load Model Specification

Modeling and Validation Subcommittee

April 2021

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This document provides the specifications for the WECC dynamic composite load model (CMPLDW) *as currently in use. This model is referred to as CMPLDW in GE PLSF™; CMLDxxU2 (where xx could be BL, AR, OW, XN or AL) in Siemens PTI PSS®E. PowerWorld and DSATools can read these models in both PSS®E and PSLF formats*

Introduction

The overall structure of the CMPLDW model is shown in Figure 1. The "System Bus" is the bus where the load is located in the power flow model. The rest is part of the model. Any power flow load can be represented in dynamic simulations by a single CMPLDW model. All the P and Q (constant MVA, constant current, and constant admittance) of the load will be included in the model, initialized at the solved voltage at the bus. The "low-side bus" and "load bus" (also called "far-end bus") do not exist in the power flow. They are added to the system during initialization of the model. The nominal voltage for the internal buses can be set, although, the actual voltage level could be 34.5 kV, 33 kV, 12 kV.

It is important to note, while using the composite load model, the user must check the voltage level of the load bus at which the composite load model is being connected. If the distribution transformer is already modeled in the power flow file, the parameter Xxf needs to be set to zero in the dynamic file. It is also advisable that the composite load model be used only at those buses at which the pu voltage in the power flow solution is above a certain pu level, and the P/Q ratio is above a certain threshold. These checks ensure the composite load model will be initialized without error during dynamic studies. For example, the composite load model for the WECC case can be applied to all buses with a load greater than 5 MW, voltage greater than 0.98 pu, and a P/Q ratio greater than 1.61 (P/Q= 1.61 ~ 0.85 pu.). In PSLF, the minimum megawatt threshold can be adjusted by setting the dypar[0].cmp_pmin prior to initialization and the minimum P/Q ratio can be adjusted by setting the dypar[0].cmp_pqmin prior to initialization.

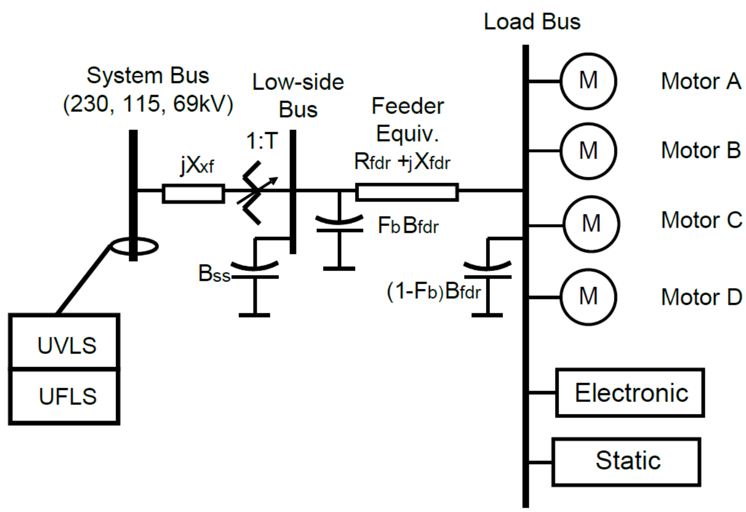

Figure 1: CMPLDW model structure

Substation and Feeder Model

A single substation transformer, substation shunt capacitor, and an equivalent distribution feeder can be represented by the model. Any of these can be omitted by setting their input parameters to zero.

Substation Transformer Model

The transformer is modeled as an on-load tap changing (LTC) transformer that can regulate its low-side voltage. A compensating impedance can be input to represent line-drop compensation. The input parameters for the transformer are:

MVA = xxx MVA base for the transformer (also used for shunt capacitance and feeder)

The following options are provided for specifying the MVA base:

xxx > 0	xxx is the MVA base
xxx < 0	abs(xxx) is the loading factor – MVA base = load MW / abs(xxx)
xxx = 0	loading factor = default value of 0.8
Xxf	transformer reactance – pu of xfmr MVA base. If Xxf = 0., transformer is omitted. (Note: xfmr R = 0.)
Tfixhs	fixed xfmr tap ratio on high-voltage side
Tfixls	fixed xfmr tap ratio on low-voltage
side LTC	LTC flag – (non-zero=active during both initialization and dynamic run; 0=active during initialization and inactive during dynamic run) -PSLF LTC flag – (1=active during both initialization and dynamic run; 0=inactive during initialization and dynamic run, -1=) active during initialization and inactive during dynamic run)- PSS®E
Tmin	LTC minimum tap (pu)
Tmax	LTC maximum tap (pu)
Step	LTC step size (pu) Vmin
Vmin	LTC Vmin (low side pu)
Vmax	LTC Vmax (low side pu)
Tdel	LTC time delay to initiate tap adjustment (sec.)
Ttap	LTC time delay between tap steps (sec.)
Rcmp	LTC compensating resistance
Xcmp	LTC compensating reactance (pu). If Rcmp and/or Xcmp are non-zero, the LTC regulates the value ofVls – (Rcmp + j Xcmp) * Ils. Where Vls is the voltage at the low-side bus and Ils is the complex current arriving at the low-side bus on the transformer

If the transformer is included (Xxf> jumper impedance) and Vmax > Vmin + 2*step, the (low-side) variable tap will be adjusted to set the low-side voltage at approximately the midpoint of Vmin -- Vmax unless Tmin or Tmax is exceeded. During dynamic simulation, If LTC = 1, the transformer tap moves in discrete steps to control the low-side voltage. If the voltage is less than Vmin or greater than Vmax for a period greater than Tdel, the transformer tap moves in steps until the voltage is within range. Ttap is the delay time between successive tap step movements.[1]

Substation Shunt Capacitor

A single shunt capacitor is represented on the low-side bus with a susceptance of Bss per unit on the transformer MVA base.

Distribution Feeder Equivalent

As indicated in Figure 1, the feeder equivalent includes series resistance and reactance and shunt capacitors at both ends. The input parameters are:

Rfdr	feeder R (pu of MVA base)
Xfdr	feeder X (pu of MVA base)
Fb	fraction of feeder reactive compensation applied at the substation end of the feeder

The value of the total feeder reactive compensation (Bfdr) is computed during initialization of the model to balance the reactive consumption of the load devices and of the transformer and feeder with the load Q value specified in the power flow data. If Fb is not zero, iteration is required to obtain the specified distribution of Bfdr between the two ends. If Xfdr = 0., the feeder is omitted, but the feeder reactive compensation is included as a single shunt element. Note, in PSS®E, the parameter FB is always set to 0.

Note that, although the user specifies the values of Rfdr and Xfdr, the software tools will adjust these values during initialization to ensure that the voltage at the load bus of the composite load model (see Figure 1) does not drop below 0.95 pu. The changes are reported by some but not all software tools in the initialization report.[2]

A detailed description of the process to initialize the distribution equivalent transformer, feeder, and two additional buses can be found in the PowerWorld WebHelp Manual.[3] The final page of the reference provides a step-by-step process for initializing.

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[1] GE PSLF™ User's Manual

[2] *Technical Guide on Composite Load Modeling*: EPRI, Palo Alto, CA: 2017. 3002019209

[3] PowerWorld WebHelp Manual

Load Component Models

The load at the far-end load bus can be represented by a combination of static load model, electronic load model, and up to four motor models, any of which can be either a three-phase motor or a single-phase air conditioner (A/C) performance-based model. The fraction of the load P represented by each model is specified by the following input parameters:

Fma	Motor A fraction
Fmb	Motor B fraction
Fmc	Motor C fraction
Fmd	Motor D fraction
Fel	Electronic load fraction

If these fractions sum to less than 1, the remainder is represented by the static load model.

If these fractions sum to more than 1, the static load fraction is set to zero and the other fractions are normalized to sum to 1.

For each motor model, the type of motor is indicated by the input parameters: Mtypa, Mtypb, Mtypc, and Mtypd. A value of 3 indicates the three-phase motor model, 1 indicates that single-phase A/C performance-based model, and other values may be used in the future for other types of models.

Static Load Model

The input parameters for the static load model are as follows:

PFs	Power Factor
P1e	P1 exponent
P1c	P1 coefficient
P2e	P2 exponent
P2c	P2 coefficient
Pfrq	P frequency sensitivity
Q1e	Q1 exponent
Q1c	Q1 coefficient
Q2e	Q2 exponent
Q2c	Q2 coefficient
Qfrq	Q frequency sensitivity

The static load model is represented by the following equations:

$Psto = Pload\ (1. - Fma - Fmb - Fmc - Fmd - Fel)$

$Po = Psto / (P1c * (Vo)^{P1e} + P2c * (Vo)^{P2e} + P3)$ (where Po is the power at 1 pu terminal voltage)

$Qo = Po * \tan(\mathrm{acos}(PFs))$

$$P = Po * (P1c * (V)^{P1e} + P2c * (V)^{P2e} + P3) * (1 + Pfrq * \Delta f)$$

$Q = Qo * (Q1c * (V)^{Q1e} + Q2c * (V)^{Q2e} + Q3) * (1 + Qfrq * \Delta f)$

$P3 = 1. – P1c – P2c$

$Q3 = 1. – Q1c – Q2c$

Pload is the initial value of P at the far-end load bus. Vo is the initial value of V at the far-end load bus. Note that the value Po in the equations above is calculated as:

Electronic Load Model

The input parameters for the electronic load model are as follows:

PFel	Electronic load power factor
Vd1	Voltage below which electronic load decreases (pu)
Vd2	Voltage below which electronic load is zero (pu)
frcel	Fraction of electronic load that recovers from low voltage trip

The logic for the electronic load model low voltage tripping is as follows:

```
 If (V < Vmin) Vmin = V                    [Initially, Vmin = Vo]
 If( Vmin < Vd2) Vmin = Vd2              [Vmin tracks the lowest voltage during the
                                                    simulation but not below Vd2]

  If (V < Vd2)
        Fv1 = 0.0                        [All load is tripped for V below Vd2] else if (V< Vd1)
  Else If (V<vd1)
       if (V <= Vmin)            [While decreasing between Vd1 and Vd2]
        Fv1 = (V – Vd2)/ (Vd1 - Vd2)
       else                           [While recovering above Vmin, partial reconnection]
        Fv1 = (( Vmin – Vd2) + frcel * (V – Vmin)) / (Vd1 – Vd2)
       endif
 else
        if (Vmin >= Vd1)
                Fv1 = 1.0         [if V has not gone below Vd1]
        else                         [V has been below Vd1 but has recovered]
                Fv1 = ((Vmin – Vd2) + frcel * (Vd1 – Vmin) / (Vd1 – Vd2)
        endif
endif
Pel = Fv1 * Pe10
Qel = Fv1 * Qe10
```

Note: The Vmin used in the pseudocode is an internal variable not to be confused with the Vmin used for the transformer model. More details on this model can be found in the PowerWorld WebHelp Manual.[4]

Three-phase Motor Model

The three-phase motor models are not exactly the same in PSS®E and PSLF. PSS®E uses the CIM5/6 family of the three-phase induction motor model to represent the three-phase motors in the composite load model; PSLF uses the Motorw model. The CIM5/6 models are fundamentally different than Motorw, which has additional approximations. It is being proposed that the future versions of the composite load model in PSLF will use the Motor1 equations, which are similar to the CIM5/6 model family in PSS®E. To that end, a new three-phase motor model that uses the same equations as the CIM5/6 family has been implemented in PSLF as a component of the modular composite load model, cmpldw2 (called cmp_mo3_2), currently in beta state, and will be available in Version 23 and higher. The three-phase motor model block diagram is shown in Figure 2. The input parameters for this model are as follows:

LFm	Loading factor – used to set motor MVA base
Rs	Stator resistance (pu)
Ls	Synchronous reactance (pu)
Lp	Transient reactance (pu)
Ll	Leakage reactance (pu)[5]
Lpp	Subtransient reactance (pu)
Tpo	Transient open circuit time constant (sec.)
Tppo	Subtransient open circuit time constant (sec.)

[4] PowerWorld WebHelp Manual

[5] Ll is not required in cmpldw or CMLDXXU2, but is an input parameter for CMLDXXDGU2

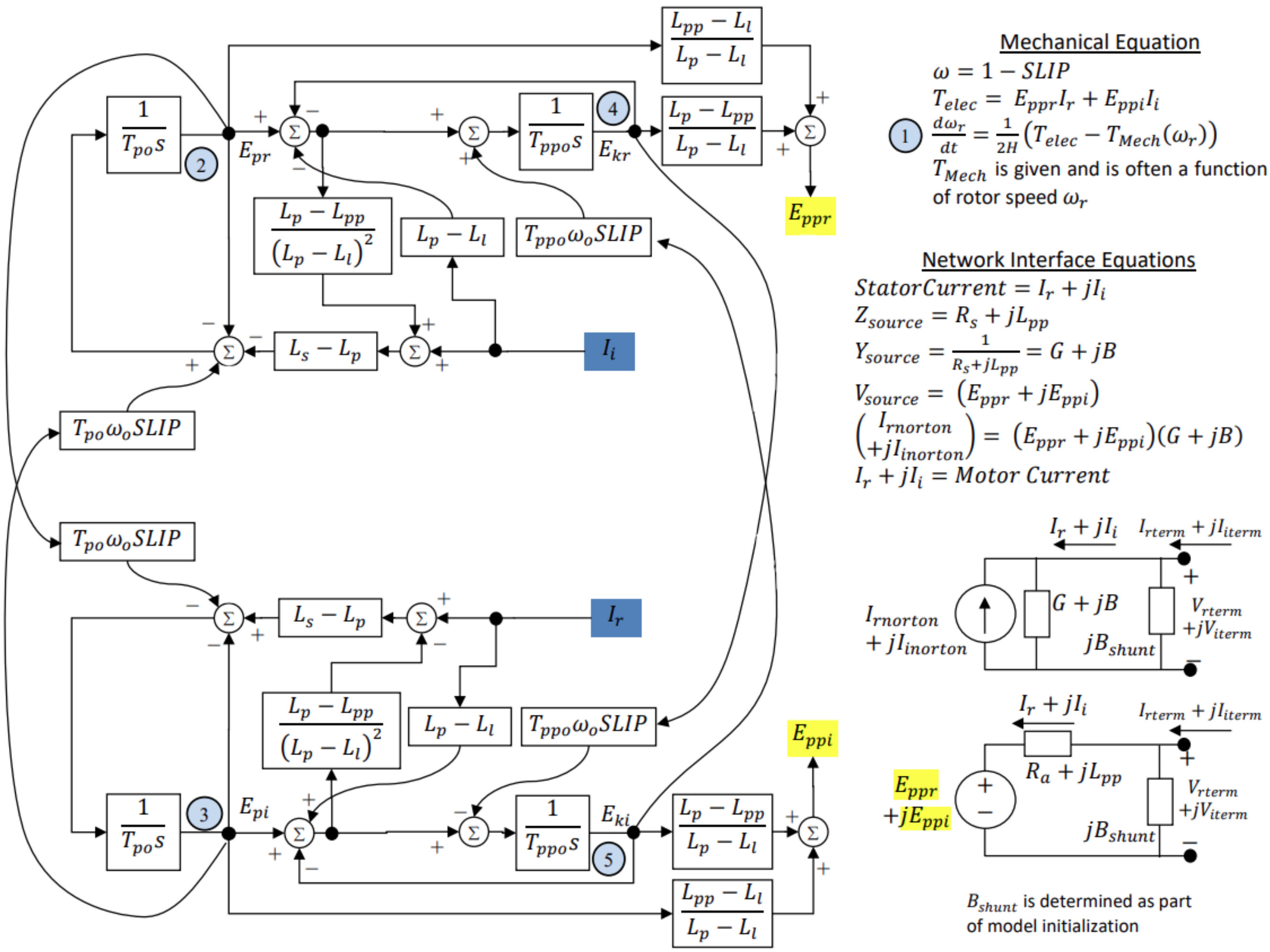

Figure 2: Three-phase motor electrical model in PSS®E

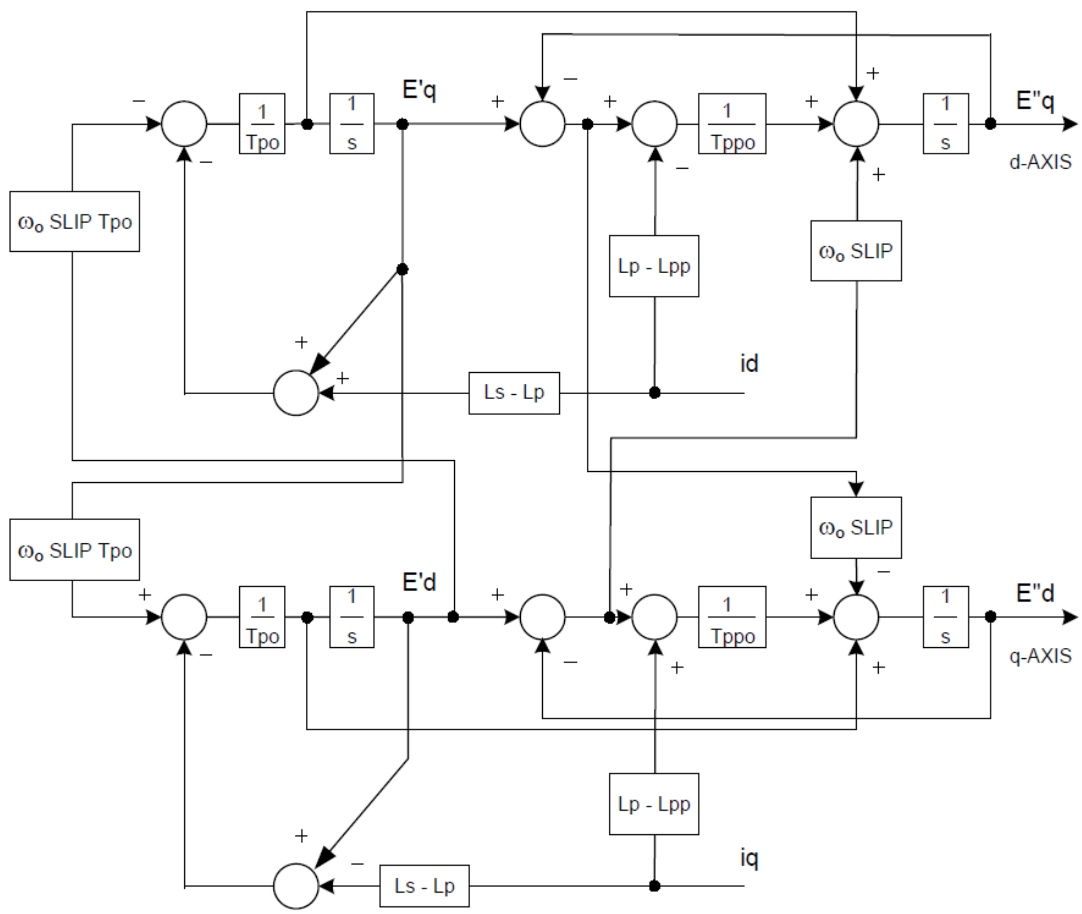

Figure 3: Three-phase motor electrical model in PSLF

In the block diagram above, the three-phase induction motor model in PSS®E (Figure 2) requires a parameter leakage reactance Ll. In the CMLDXXU2 model the leakage reactance (Ll) is set equal to 0.80 times Lpp'' for double cage machine, 0.6 times Lp' for a single cage. However, this parameter is an input parameter for the CMLDXXDGU2 model. Also note that if Lp=Lpp in the above models or if Tppo=0, the three-phase motor model is treated as a single cage three-phase induction motor. In PSLF (Figure 3) the parameter Ll is not needed since the three-phase motor model in PSLF (Motorw) uses a different set of assumptions. However, as mentioned before, the new version of the motor model in the modular cmpldw2 in PSLF (cmp_mo3_2) has Ll as an input parameter that is set to a default of up to 0.80 times Lpp if no input value for Ll is provided.

The input parameters for the mechanical model are:

H	Inertia constant (sec.)
Etrq	Speed exponent for mechanical torque.

The equations for the mechanical model are:

$$Tm = Tmo \times \omega^{Etrq}$$

$$\frac{d\omega}{dt} = \frac{(Te - Tm)}{2H}$$

The value of *Tmo* is calculated as part of the initialization. Initializing this model gives a rotor speed and electrical power being transmitted to the mechanical load. The *Tmo* is calculated from this.

Two levels of undervoltage tripping are represented with the following input parameters:

Vtr1x	First U/V Trip V (pu)
Ttr1x	First U/V Trip delay time (sec)
Ftr1x	First U/V Trip fraction
Vrc1x	First U/V reconnection V (pu)
Trc1x	First U/V reconnection delay time (sec)
Vtr2x	Second U/V Trip V (pu)
Ttr2x	Second U/V Trip delay time (sec)
Ftr2x	Second U/V Trip fraction
Vrc2x	Second U/V reconnection V (pu)
Trc2x	Second U/V reconnection delay time (sec)

The fractions tripped by each level are cumulative.

Single-phase Air Conditioner Performance-based Model

The single-phase A/C performance-based model was developed by WECC Load Modeling Task Force members based on extensive laboratory testing of a variety of A/C units. The model is intended to represent a composite of many individual single-phase A/C compressors and their protective devices as shown schematically in Figure 4.

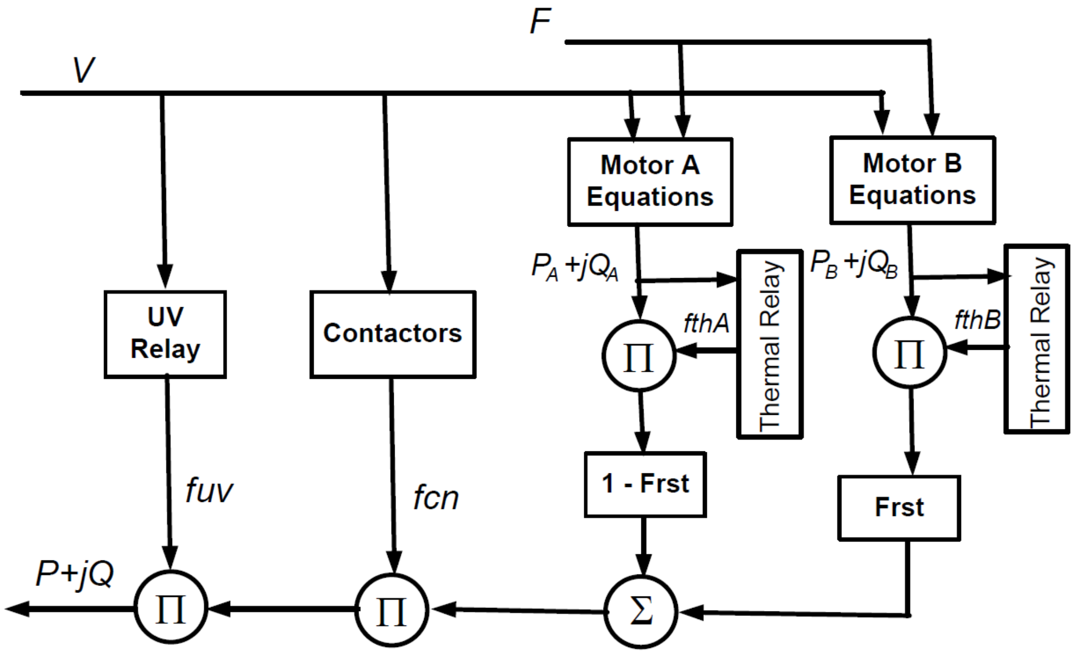

Figure 4: CMPLDW 1-Phase A/C Performance-based Model Schematic

The compressor motor model is divided into two parts:

Motor A	Those compressors that cannot restart soon after stalling
Motor B	Those compressors that can restart soon after stalling

The motors are represented by algebraic equations, as follows:

If V > 0.86:

$$P = Po \times (1 + \Delta f)$$

$$Q = [Q'o + 6 \times (V - 0.86)^2] \times (1 - 3.3 \times \Delta f)$$

If V < 0.86 and V > V'stall:

$$P = [Po + 12 \times (0.86 - V)^{3.2}] \times (1 + \Delta f)$$

$$Q = [Q'o + 11 \times (0.86 - V)^{2.5}] \times (1 - 3.3 \times \Delta f)$$

If V < V'stall:

$$P = Gstall \times V \times V$$

$$Q = -Bstall \times V \times V$$

If V < Vstall for t > Tstall, motor stays in stalled state.

For "B" motor, if V > Vrst for t > Trst, the motor restarts.

Note that *Δf* in this equation is calculated as *f-1,* which means *Δf* is negative for an underfrequency event. Also, if Tstall is less than zero, a voltage-and-time-dependent stall characteristic is used, as shown in Figure 5.

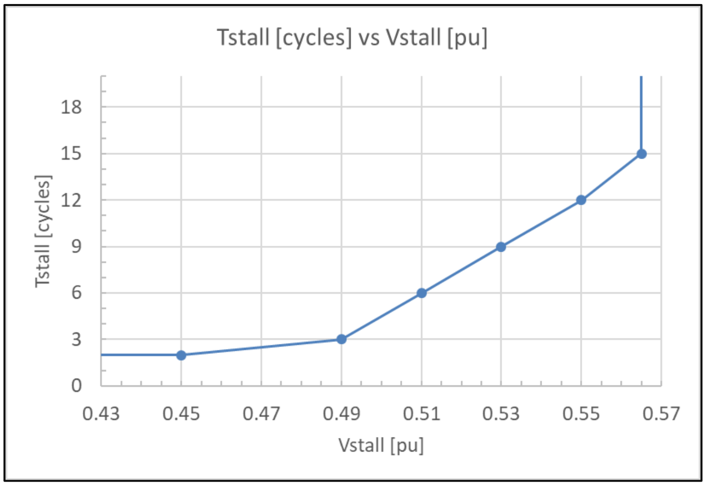

Figure 5: Inverse time Vstall-Tstall characteristic used when tstall = -1

Initialization calculations:

$$Q'o = Po \times \tan(acos(CompPF)) - 6 \times (1 - 0.86)^2$$

The three code segments above show the three different characteristics of the motor D model, called the run state I, the run state II, and the stall state. The point at which the stall state curve and the run state II curve intersect is called the Vstallbrk point. This intersection point is calculated during initialization by the software programs using an iterative scheme similar to the one shown below[6]:

```
for ( V = 0.4; V < Vstall; V += 0.01 )
        {
        pst = Gstall * V^2
        p_comp = Po + 12 * (0.86 – V)^3.2
        if ( p_comp <= pst )
                {
                V'stall = V
                break
                }
        }
```

The algorithm above shows the calculation of this intersection to be precision of 0.01 per unit voltage. Note that this algorithm is only indicative, and software vendors may use different algorithms to

[6] *Technical Guide on Composite Load Modeling*: EPRI, Palo Alto, CA: 2017. 3002019209

calculate Vstallbrk. For example, some software vendors use Newton's method to solve for this intersection point to a hard-coded accuracy in per unit instead (PowerWorld Simulator uses a precision 0.0001 per unit voltage). The input parameters for the single-phase A/C model are as follows :

LFm	Loading factor – used to set MVA base
CompPF	Power factor
Vstall	Stall voltage (pu)
Rstall	Stall resistance (pu)
Xstall	Stall reactance (pu)
Tstall	Stall time delay (sec.)
Frst	Fraction of load that can restart after stalling
Vrst	Voltage at which restart can occur (pu)
Trst	Restart time delay (sec.)
Fuvr	Fraction of load with undervoltage relay protection
Vtr1	First U/V Trip V (pu)
Ttr1	First U/V Trip delay time (sec)
Vtr2	Second U/V Trip V (pu)
Ttr2	Second U/V Trip delay time (sec)
Vc1off	Contactor voltage at which tripping starts (pu)
Vc2off	Contactor voltage at which tripping is complete (pu)
Vc1on	Contactor voltage at which reconnection is complete (pu)
Vc2on	Contactor voltage at which reconnection starts (pu)
Tth	Thermal time constant (sec)
Th1t	Thermal protection trip start level (pu temperature)
Th2t	Thermal protection trip completion level (pu temperature)
Tv	Voltage measurement lag (sec.)

Based on the values of Vstall, Tstall, Vrst, and Trst, the motor D component transitions between the run and the stall conditions. The transition of the model between the different states is explained as follows:

a. **Transition from run state to the stall state**: When the voltage at the composite load model terminal dips below the user specified *Vstall* for a duration of *Tstall*, the motor transitions to the stall condition.
b. **Transition from stall state to the run state**: When the voltage at the terminal of the composite load model at which motor D has stalled recovers over *Vrst* for a duration of ***Trst***, the restartable portion of the composite load model (as listed above) transitions back to the run state. Note that the non-restartable portion of the motor D remains stalled state for the remainder of the simulation once it has stalled.

Depending on the values of the *Vstall* and *Tstall*, the transition of motor D from a run to a stall condition can vary notably with the change in the terminal voltage.[7] These different cases are shown in Figure 6, Figure 7, and Figure 8. More details on this can be found in the *Technical Guide on Composite Load Modeling*.[8]

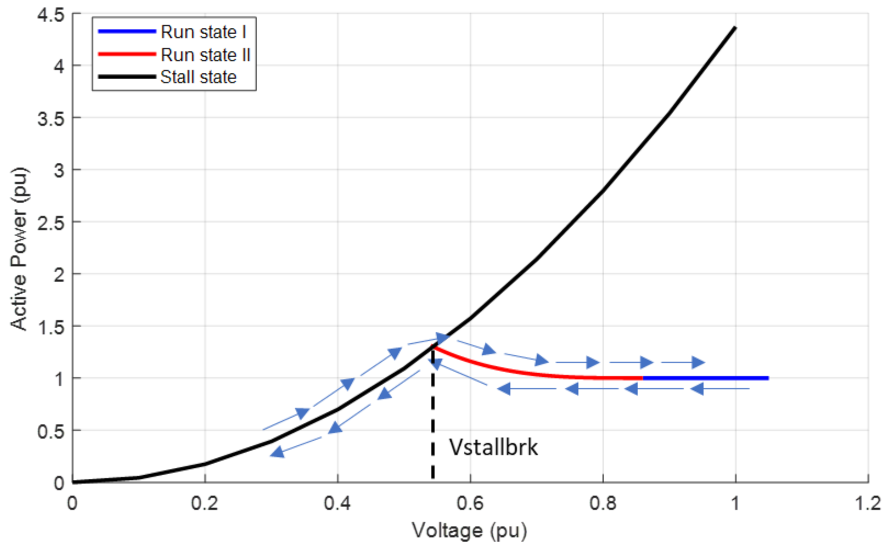

Figure 6: Motor D active power change with voltage with Vstall = any value, Tstall = 9999

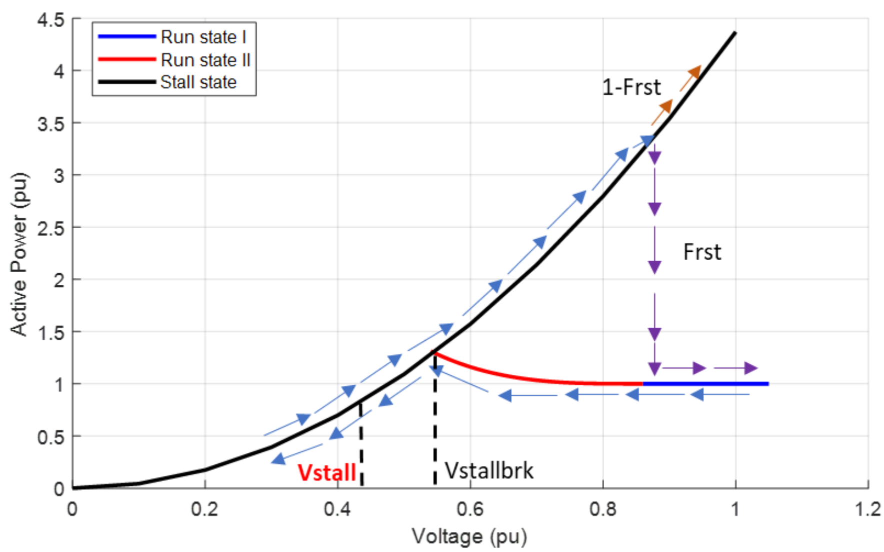

Figure 7: Motor D active power change with voltage with Vstall < Vstallbrk and Tstall = 2-3 cycles

[7] Reference: *Technical Guide on Composite Load Modeling*: EPRI, Palo Alto, CA: 2017. 3002019209

[8] Ibid

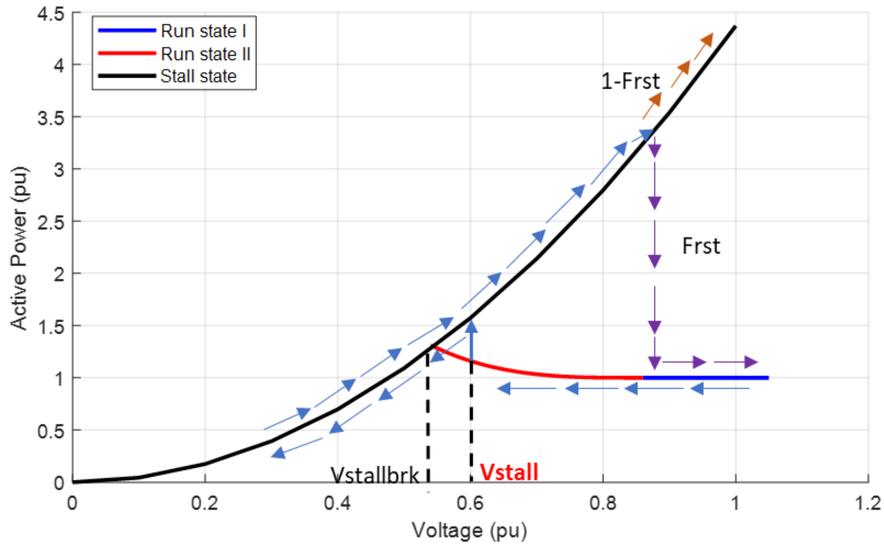

Figure 8: Motor D active power change with voltage when Vstall > Vstallbrk and Tstall = 2-3 cycles

The motor D component has an undervoltage relay representation that can be used to trip the fraction fuvr. Once tripped, the fraction fuvr does not reconnect for the remainder of the simulation. The undervoltage relay can be set by adjusting the parameter pairs vtr1, ttr1 and vtr2, ttr2. These two parameters set at inverse time characteristics, which implies that, if the voltage drops below vtr1 for time ttr1 or below vtr2 for time ttr2, the fraction fuvr trips.

The models for the contactor and thermal relays are shown in Figure 9 and Figure 10. Additional documentation on this model can be found in the PowerWorld WebHelp Manual.[9]

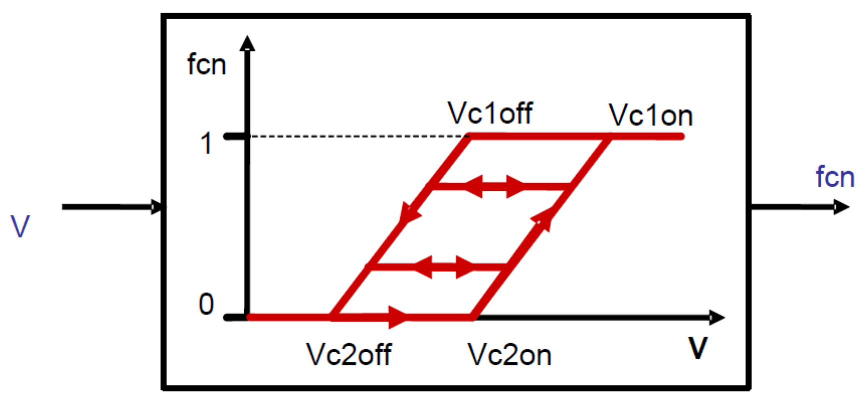

Figure 9: Contractor Model

[9] PowerWorld WebHelp Manual

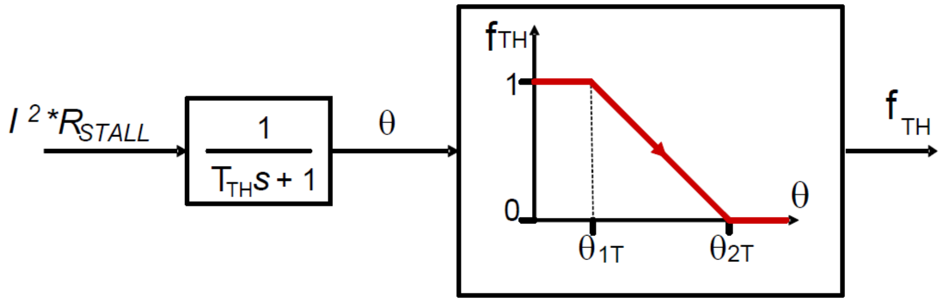

Figure 10: Thermal Relay Model

Output Variables

The following output variables should be available for plotting. Some software vendors may have provisions to monitor extra channels as well and the level of recording shown here is indicative.

Level 1	
Pld	Total MW at system bus
Qld	Total MVAr at system bus
Level 2	
Pshd	load[].pshed value for this load MW
Vls	pu voltage at substation low-side bus
Vld	pu voltage at load end of feeder
Level 3	
Pst	load[].pshed value for this load MW
Qst	pu voltage at substation low-side bus
Pel	pu voltage at load end of feeder
Qel	Electronic load MVAr
For each motor (n) in use:	
Pm*n*	Motor P, MW
Qm*n*	Motor Q, MVAr
Level 4	
For each Type 3 motor (*n*) in use:	
spd*n*	motor speed, pu
Tm*n*	Motor mechanical torque, pu
Te*n*	Motor electrical torque, pu
fuv*n*	Fraction of motor not tripped by UV relay
For each Type 1 motor(*n*) in use:	
fuv*n*	Fraction of motor not tripped by UV relay
fcn*n*	Fraction of motor not tripped by contactor
crA*n*	current in non-restarting part of load, pu

crB*n*	current in restarting part of load, pu
Level 5	
Fm*n*	Fraction of motor not tripped by load-shedding relay
Level 9—For Type 1 motors	
tmpA	temperature in non-restarting part of load, pu
fthA	Fraction of non-restarting part of load not tripped by thermal protection
tmpB	temperature in restarting part of load, pu
fthB	Fraction of restarting part of load not tripped by thermal protection

Load Shedding

If a load-shedding relay is applied to the load, the output of each of the load components is reduced in proportion to the load shed fraction. The feeders R and X are increased to simulate the effect of a fraction of the distribution feeders being tripped. The substation transformer and shunt capacitor at the substation bus are not changed.

Handling of extra vars due to end-use load tripping

During initialization of the composite load model shunt reactance is added to the feeder to match the composite load Q with the power flow Q at the power flow bus. This Q is added to Bf2 and/or Bf1 as shown in Figure 11. When each of the load component trips due to the end-use protection, this shunt capacitance is not held constant and tripped in proportion to the MW of each component tripped. An example is shown here to highlight this. Consider the CMLD/CMPLDW instance shown in Figure 11.

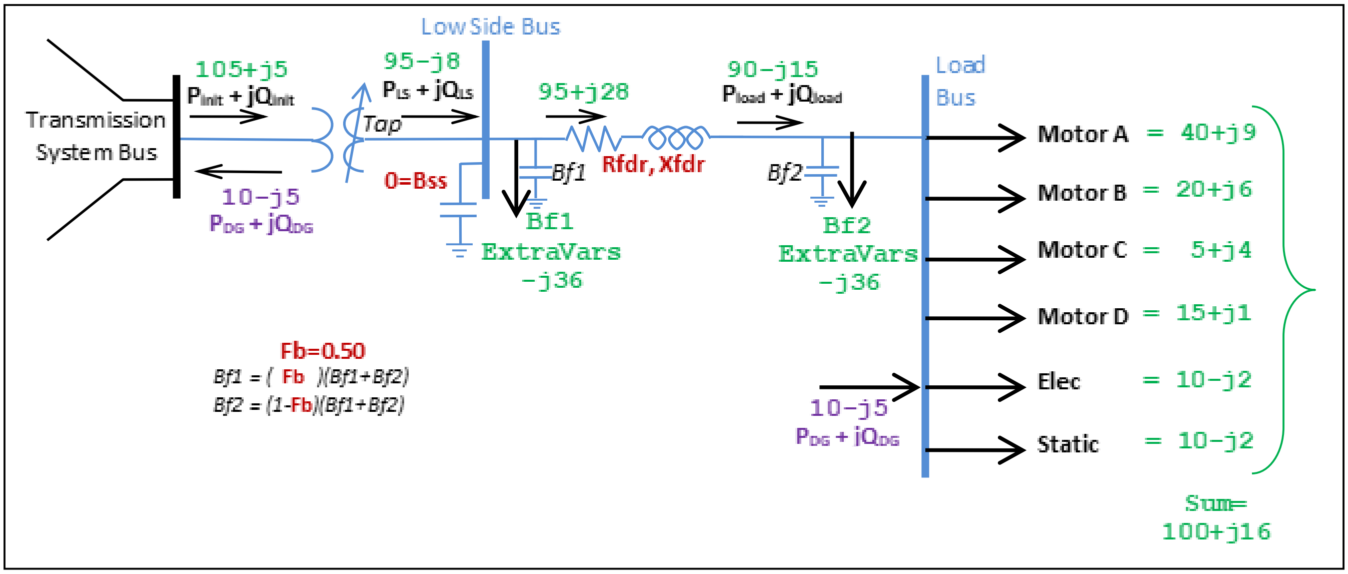

Figure 11: CMLD/CMPLDW initialization

The summation of the initial megawatt values is 100. The initial extra vars added to the model to balance Q is internally allocated to each component as follows:

	Initial MW	Initial Mvar	Initial MVA	Weighting Factor	Allocation of ExtraVars	Per Unit admittance on 100 MVA Base
Motor A	40	9	41.00	40/100 = 0.40	-14.4	0.144
Motor B	20	6	20.88	20/100 = 0.20	-7.2	0.072
Motor C	5	4	6.40	5/100 = 0.05	-1.8	0.018
Motor D	15	1	15.03	15/100 = 0.15	-5.4	0.054
Electronic	10	-2	10.20	10/100 = 0.10	-3.6	0.036
Static	10	-2	10.20	10/100 = 0.10	-3.6	0.036
Total	100	16	103.71		-36.0	0.360

Remember, for simplicity we are assuming the initial voltage per unit is 1.000 at the load bus. Otherwise, we would need to divide the per unit B values above by the square of initial voltage.

Now, assume we are at a point at which various fractions of the load components have tripped. The table below shows how the extra vars will be tripped as each component of the load model is tripped. This calculation is done internally and will not be reported by the software tool.

	Modeling ExtraVars as per unit admittance on 100 MVA base for initial condition	Fraction of Nominal Load component that is still in service (Value of 0.70 means that 30% has tripped)	New portion of "ExtraVar" Admittance from this load component
Motor A	0.144	0.20	0.0288
Motor B	0.072	0.70	0.0504
Motor C	0.018	0.40	0.0072
Motor D	0.054	1.00	0.0540
Electronic	0.036	0.80	0.0288
Static	0.036	1.00 (static is always 1.00)	0.0360
Total	0.360		0.2052

Version History

Modified Date	Modified By	Description
January 27, 2015	MVWG	Drafted and approved document
April 2021	MVS	Updated branding and added in

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