# WECC Dynamic Composite Load Model (CMPLDW) Specifications
**January 27, 2015**

This document provides the specifications for the WECC Dynamic Composite Load Model (CMPLDW in PLSF; CMLDBLU1 in PSS/E) as currently in use.

## 1. Overall Description

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. All of the rest is part of the model. Any power flow load can be represented in dynamic simulations by a single CMPLDW model. All of 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 these buses is arbitrarily set at 100kV, although the actual voltage level would be some lower value, e,g, 34.5kV, 33kV, 12kV.
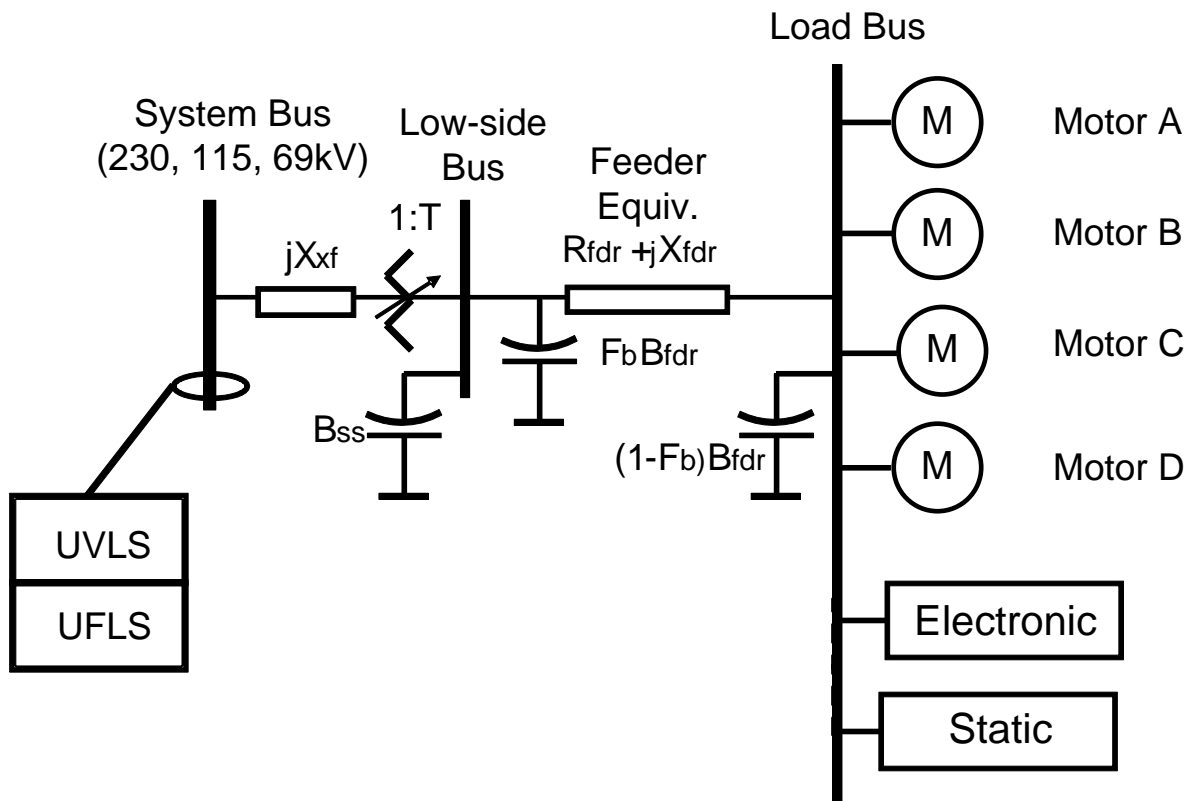


*Figure 1  CMPLDW Model Structure*

# 2. 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.

## 2.2    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 – p.u. 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 – (1=active; 0=inactive)
> Tmin      -- LTC minimum tap (pu)
> Tmax      -- LTC maximum tap (pu)
> Step      -- LTC step size (pu)
> 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 (pu)
> Xcmp      -- LTC compensating reactance (pu)
>>         If Rcmp and/or Xcmp are non-zero, the LTC regulates the value of
>>            Vls – (Rcmp + j Xcmp) * Ils

## 2.3    Substation Shunt Capacitor

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

## 2.4    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.

# 3. 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 4 motor models, any of which can be either a 3-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 3-phase motor model, 1 indicates that 1-phase A/C performance-based model, and other values may be used in the future for other types of models.

## 3.1    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:

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

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

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

$$Qo \quad = Po * \tan(\text{acos(PFs)})$$
$$P3 \quad = 1. - P1c - P2c$$
$$Q3 \quad = 1. - Q1c - Q2c$$

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.

## 3.2 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
      Pel0  -- Initial value of Pel
      Qel0  -- Initial value of Qel

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 )
    Fvl = 0.0              [All load is tripped for V below Vd2]
else if( V < Vd1 )
    if( V <= Vmin )       [While decreasing between Vd1 and Vd2]
        Fvl = (V - Vd2) / (Vd1 - Vd2)
    else                  [While recovering above Vmin, partial reconnection]
        Fvl = ( (Vmin - Vd2) + frcel * (V - Vmin) )
                     / (Vd1 - Vd2)
    endif
else
    if( Vmin >= Vd1 )
        Fvl = 1.0         [If V has not gone below Vd1]
    else                  [V has been below Vd1 but has recovered]
        Fvl = ( (Vmin - Vd2) + frcel * (Vd1 - Vmin) )
                       / (Vd1 - Vd2)
    endif
endif
Pel = Fvl * Pel0
Qel = Fvl * Qel0
```

## 3.3    Three-phase Motor Model

The 3-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)
Lpp      – Subtransient reactance (pu)
Tpo      – Transient open circuit time constant (sec.)
Tppo     – Subtransient open circuit time constant (sec.)



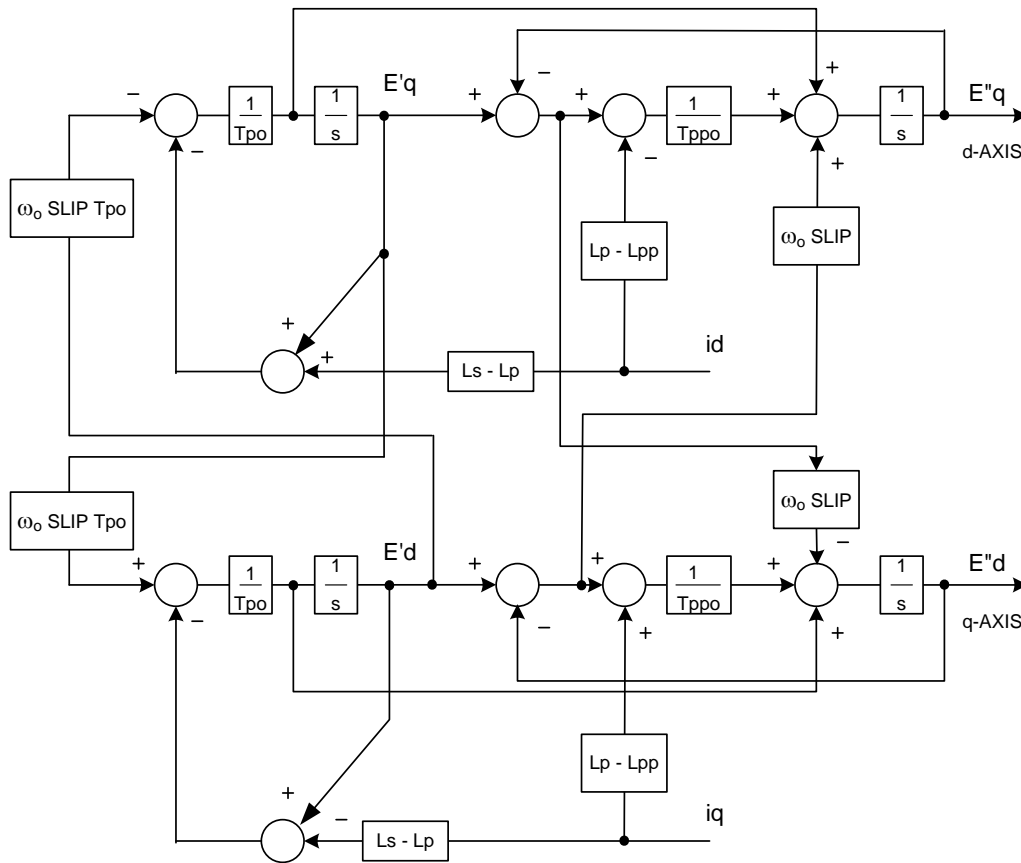*Figure 2  CMPLDW 3-Phase Motor Electrical Model*

The input parameters for the mechanical model are:

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

The equations for the mechanical model are:

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

$$d\omega/dt = (Te - Tm)/2H$$

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

Vtr1$x$ – First U/V Trip V (pu)
Ttr1$x$ – First U/V Trip delay time (sec)
Ftr1$x$ – First U/V Trip fraction
Vrc1$x$ – First U/V reconnection V (pu)
Trc1$x$ – First U/V reconnection delay time (sec)
Vtr2$x$ – Second U/V Trip V (pu)
Ttr2$x$ – Second U/V Trip delay time (sec)
Ftr2$x$ – Second U/V Trip fraction
Vrc2$x$ – Second U/V reconnection V (pu)
Trc2$x$ – Second U/V reconnection delay time (sec)

The fractions tripped by each level are cumulative.

## 3.4 Single-phase Air Conditioner Performance-based Model

The 1-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 3.
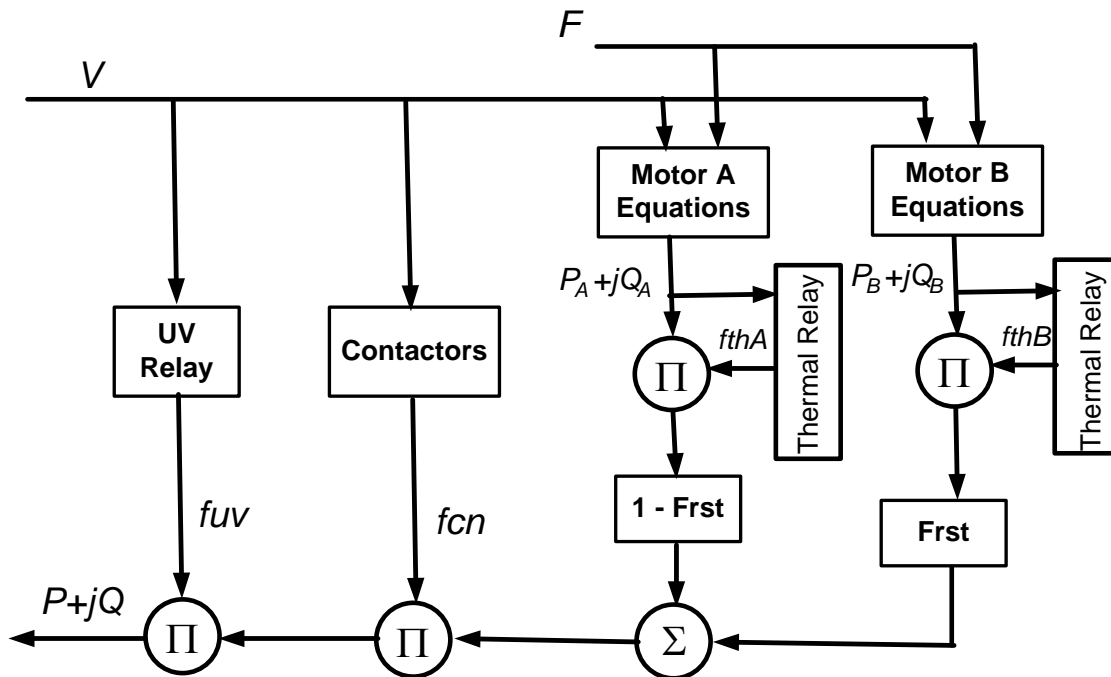


***Figure 3  CMPLDW 1-Phase A/C Performance-based Model Schematic***

The compressor motor model is divided into two parts:

Motor A – Those compressors that can't 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:

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

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

If V < 0.86 and V > V'stall:

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

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

If V < V'stall:

$$P = Gstall * V * V$$

$$Q = - Bstall * V * V$$

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

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

Initialization calculations:

$$Q'o = Po * \tan(\mathrm{acos}(CompPF)) - 6 * (1. - 0.86)^2$$

V'stall is calculated to determine the voltage level at which there is an intersection between the stall power characteristic and the transition characteristic used for V < 0.86:

```
for ( V = 0.4; V < Vstall; V += 0.01 )
        {
        pst = Gstall * V²
        p_comp = Po + 12 * (0.86 – V) ³·²
        if ( p_comp < pst )
                {
                V'stall = V
                break
                }
        }
```

The input parameters for the 1-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.)

Both levels of undervoltage protection trip the same fraction of the motor load (not cumulative) and no reconnection occurs.

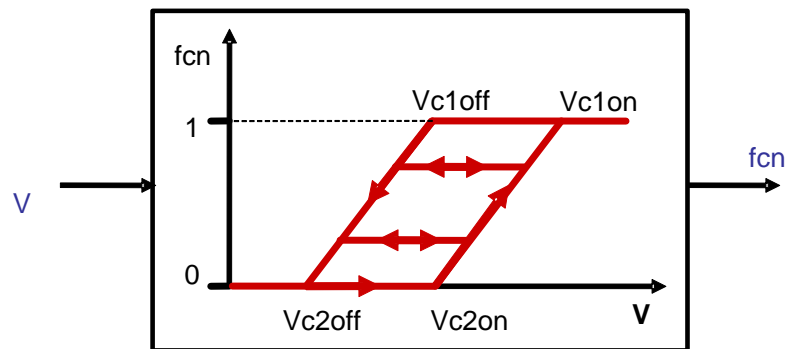The models for the contactor and thermal relays are shown in Figures 4 and 5.
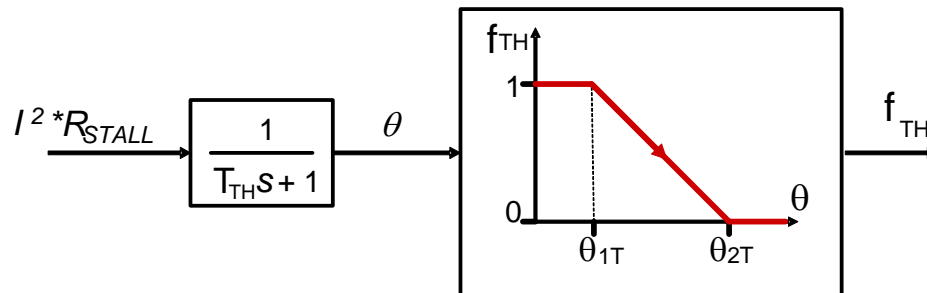


*Figure 4  Contactor Model*



*Figure 5  Thermal Relay Model*

# 4. Output Variables

The following output variables should be available for plotting:
**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 | – Static load component MW |
| Qst | – Static load component MVAr |
| Pel | – Electronic load MW |
| 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 |

# 5. 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 feeder R and X are increased to simulate the effect of a fraction of the distribution feeders being tripped.  The substation transformer and shunt capacitor are not changed.