# Dynamic Load Models in PowerWorld Simulator

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# Modular Structure of Generator Dynamic Models

- Generators have included a modular structure for several decades (1970s and onward)
- Synchronous generators had up to 8 separate modules with coordinated initialization
  - Machine
  - Exciter
  - Governor
  - Stabilizer
  - Under Excitation Limiter
  - Over Excitation Limiter
  - Compensator Model
  - Relay Model
- Even more have been added recently
  - Aerodynamic Model (Type 3 Wind)
  - Pref Controller (Type 3 wind and LCFB1)
  - Plant Controller (renewable models)
  - AGC Controller (Implemented in Version 19 of PowerWorld Simulator)

# Load Models have not kept up

- Load Models have been stuck with only two modules
  - Load characteristic
  - Load relay
- The MOTORW model introduced in PSLF in the 1990s was a step in the right direction
  - MOTORW included a parameter indicating what *percentage* of the load was a motor
  - This meant we now had 3 modules
    - Dynamic Model
    - Algebraic Model
    - Relay Model
  - No longer required you to split the power flow load record to permit a load model split

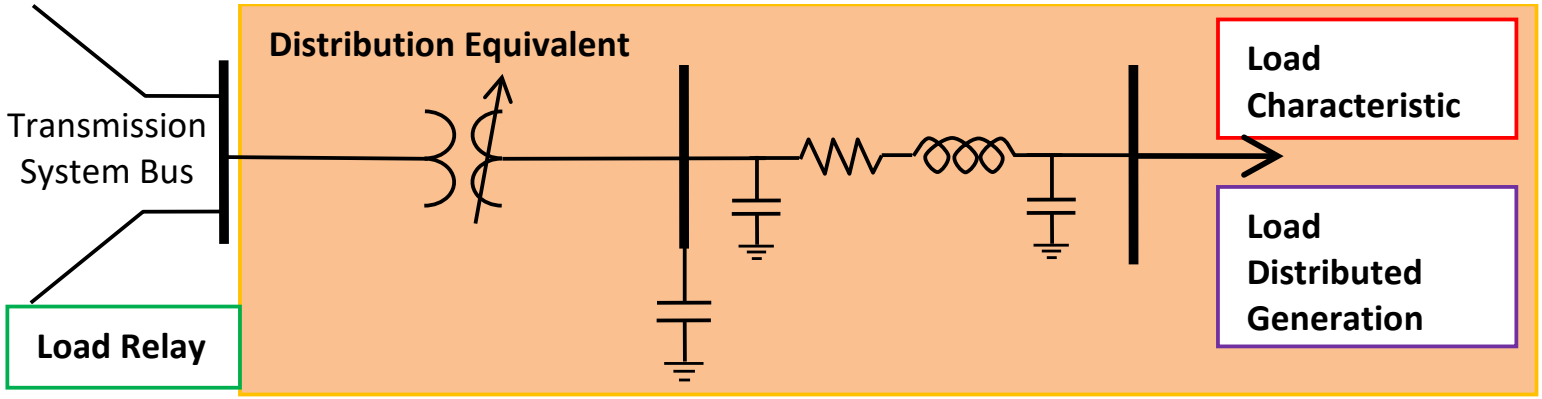
# Initial Implementation of Distribution Equivalent

- Composite load model (CMPLDW) was designed within the WECC LMTF in the mid 2000s
  - The distribution equivalent is stuck inside the load characteristic
  - Has meant that new load models in WECC are gravitating toward being smashed into the CMPLDW framework
- Load Distributed Generation (Roof-top Solar for example)
  - This also needs to be at the end of Distribution Equivalent

# It is Time to Modularize: Just like Generators

- Natural for a load record to have 4 modules associated with transient stability
  - Load Characteristic
    - Ability to generically split up into any combination of components will be available in PowerWorld Simulator Version 20 in Summer 2017
  - Relay Model
  - Distribution Equivalent
    - Added in PowerWorld Simulator Version 17 in January 2013
  - Load Distributed Generation Model
    - Added in PowerWorld Simulator Version 19 in November 2015

Attributes of a load are not always related to one another and thus independent dynamic models should be available



# Load Record: Distributed Generation

- Discussed in WECC LMTF for a few years and decision was made in 2014 to model with three new user input fields with each Load Record
  - **Dist MW Input**: the user entered MWs of distributed generation at the load
  - **Dist Mvar Input**: the user entered Mvars of distributed generation at the load
  - **Dist Status**: The status of the distributed generation (Open or Closed)
- Available in PowerWorld Simulator 19 in year 2015

| | Number of Bus | Name of Bus | Area Name of Load | Zone Name of Load | ID | Status | MW | Mvar | MVA | S MW | S Mvar | Dist Status | Dist MW Input | Dist Mvar Input | Dist MW | Dist Mvar | Net Mvar | Net MW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | Two | Top | 1 | 1 | Closed | 80.00 | 20.00 | 82.46 | 80.00 | 20.00 | Closed | 40.00 | 0.00 | 40.000 | 0.000 | 20.000 | 40.000 |
| 2 | 3 | Three | Top | 1 | 1 | Closed | 220.00 | 40.00 | 223.61 | 220.00 | 40.00 | Open | 110.00 | 0.00 | 0.000 | 0.000 | 40.000 | 220.000 |
| 3 | 4 | Four | Top | 1 | 1 | Closed | 160.00 | 30.00 | 162.79 | 160.00 | 30.00 | Closed | 80.00 | 0.00 | 80.000 | 0.000 | 30.000 | 80.000 |
| 4 | 5 | Five | Top | 1 | 1 | Closed | 260.00 | 40.00 | 263.06 | 260.00 | 40.00 | Open | 130.00 | 0.00 | 0.000 | 0.000 | 40.000 | 260.000 |
| 5 | 6 | Six | Left | 1 | 1 | Closed | 400.00 | 0.00 | 400.00 | 400.00 | 0.00 | Closed | 200.00 | 0.00 | 200.000 | 0.000 | 0.000 | 200.000 |
| 6 | 7 | Seven | Right | 1 | 1 | Closed | 400.00 | 0.00 | 400.00 | 400.00 | 0.00 | Closed | 200.00 | 0.00 | 200.000 | 0.000 | 0.000 | 200.000 |

# Other Load Record Fields

- **Dist MW**, **Dist Mvar**: this is the actual MWs being seen by the power flow solution
  - This will be 0.0 if **DistStatus** = Open
  - This will be reduced if the voltage falls below the minimum voltage for constant power load
- **Net MW**: this is equal to the subtraction of the fields **MW** – **Dist MW**
- Net Mvar: this is equal to the substraction of the fields Mvar – Dist Mvar

| | Number of Bus | Name of Bus | Area Name of Load | Zone Name of Load | ID | Status | MW | Mvar | MVA | S MW | S Mvar | Dist Status | Dist MW Input | Dist Mvar Input | Dist MW | Dist Mvar | Net Mvar | Net MW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | Two | Top | 1 | 1 | Closed | 80.00 | 20.00 | 82.46 | 80.00 | 20.00 | Closed | 40.00 | 0.00 | 40.000 | 0.000 | 20.000 | 40.000 |
| 2 | 3 | Three | Top | 1 | 1 | Closed | 220.00 | 40.00 | 223.61 | 220.00 | 40.00 | Open | 110.00 | 0.00 | 0.000 | 0.000 | 40.000 | 220.000 |
| 3 | 4 | Four | Top | 1 | 1 | Closed | 160.00 | 30.00 | 162.79 | 160.00 | 30.00 | Closed | 80.00 | 0.00 | 80.000 | 0.000 | 30.000 | 80.000 |
| 4 | 5 | Five | Top | 1 | 1 | Closed | 260.00 | 40.00 | 263.06 | 260.00 | 40.00 | Open | 130.00 | 0.00 | 0.000 | 0.000 | 40.000 | 260.000 |
| 5 | 6 | Six | Left | 1 | 1 | Closed | 400.00 | 0.00 | 400.00 | 400.00 | 0.00 | Closed | 200.00 | 0.00 | 200.000 | 0.000 | 0.000 | 200.000 |
| 6 | 7 | Seven | Right | 1 | 1 | Closed | 400.00 | 0.00 | 400.00 | 400.00 | 0.00 | Closed | 200.00 | 0.00 | 200.000 | 0.000 | 0.000 | 200.000 |

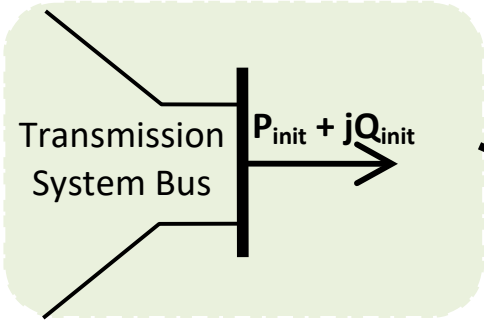
# Treatment of Distributed Generation in Power Flow

- Summary Information with Areas, Zones, Substations, etc…
  - Dist MW is separate summation from Load MW

| | Area Num | Area Name | AGC Status | Gen MW | Load MW | Dist MW | Shunt MW | Tot Sched MW | Int MW | ACE MW | Lambda | Loss MW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Top | ED | 367.42 | 720.00 | 120.000 | | 0.00 | -359.54 | -359.54 | 0.00 | 6.96 |
| 2 | 2 | Left | ED | 199.52 | 400.00 | 200.000 | | 0.00 | -200.82 | -200.82 | 0.00 | 0.34 |
| 3 | 3 | Right | ED | 400.99 | 400.00 | 200.000 | | 0.00 | 0.36 | 0.36 | 0.00 | 0.64 |

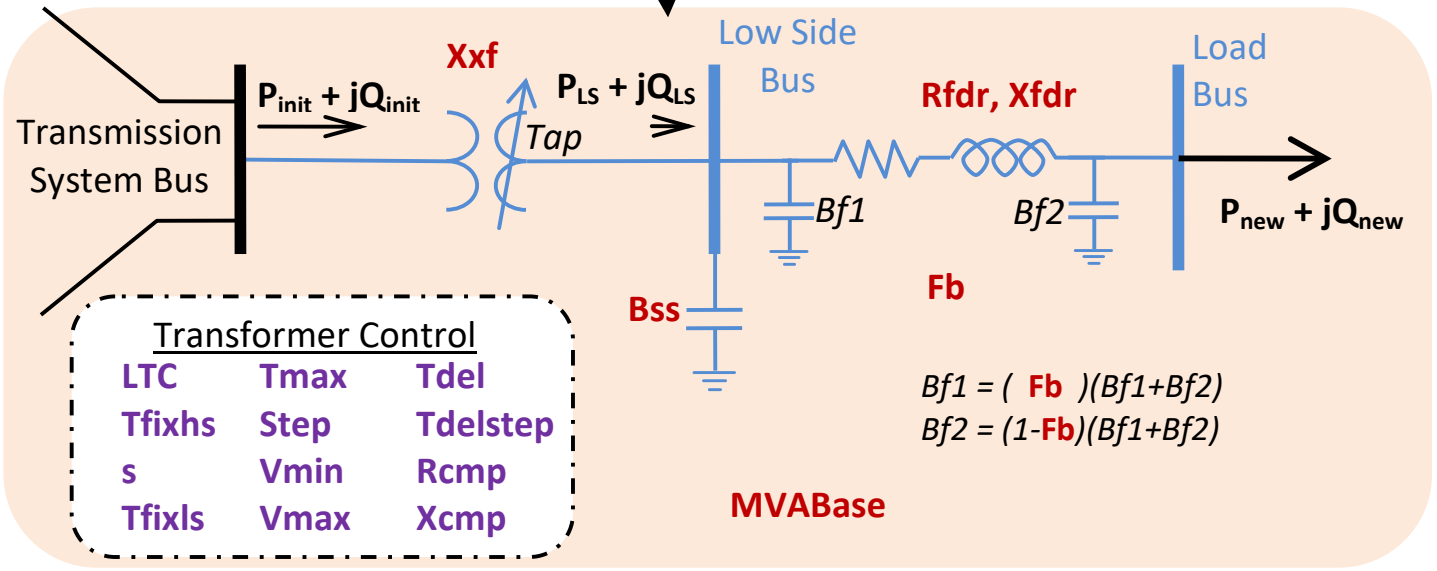
- Injection Group Treatment
  - Injected MW = Gen MW – Load MW – Dist Gen MW
- Contingency Actions
  - “Set, Change, Move” actions only act on Load portion
  - Open and Close actions also open the distributed gen

# Load Distribution Equivalent




The internal model used by the transient stability numerical simulation structurally does the following.

1. Creates two buses called Low Side Bus and Load Bus
2. Creates a transformer between Transmission Bus and Low Side Bus
3. Creates a capacitor at the Low Side Bus
4. Creates a branch between Low Side Bus and Load Bus
5. Moves the Load from the Transmission Bus to the Load Bus



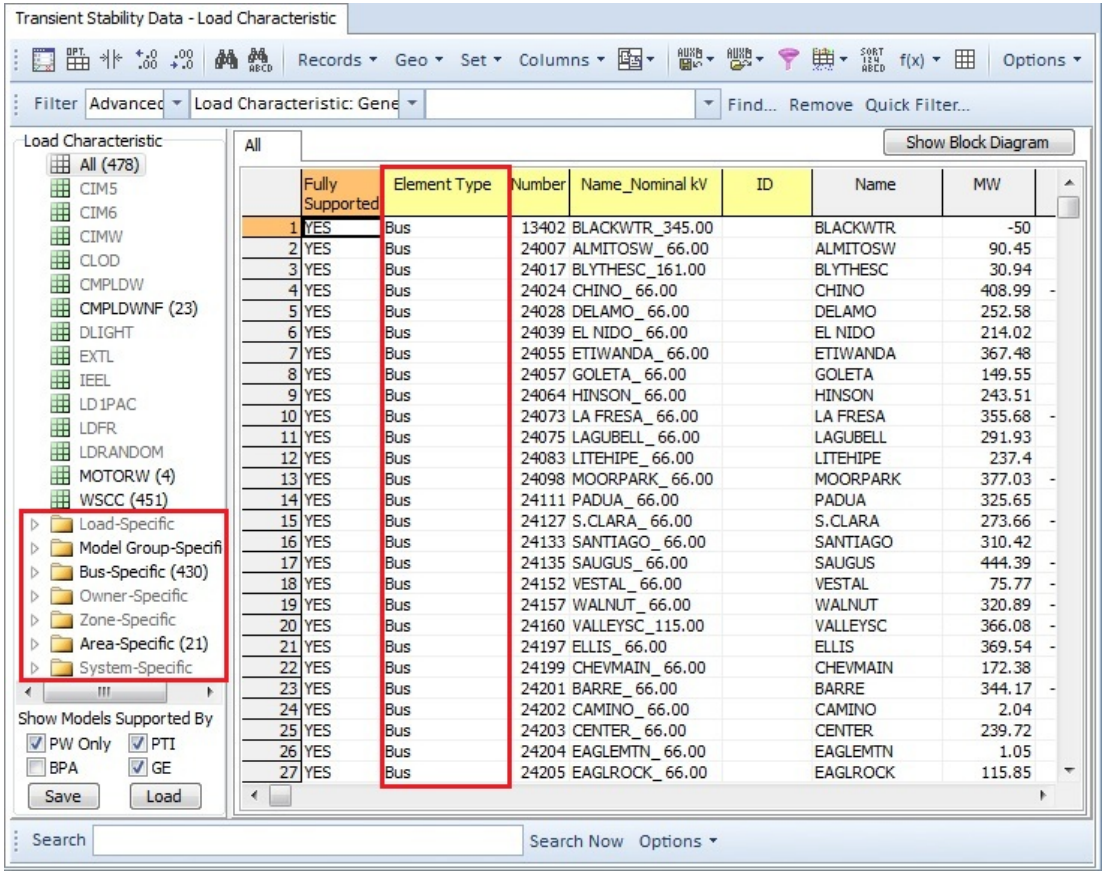
# Load Model Features for Data Management

- Dynamic model structure for loads: 4 model types
  - Load Characteristic
    - Describes load behavior (CMPLDW, WSCC, MOTORW, CIM5, CIM6,etc)
    - Can be assigned in hierarchy levels (Load Model Group, Bus, Owner, Zone, Area, System)
  - Load Distribution Equivalent
    - Assigned to the load record
    - Not part of load characteristic, so can be used in combination with any load characteristic
  - Load Distributed Generation
    - Describes the behavior of the distributed generation
  - Load Relay
- Load Model Group
  - Special named object that contains Characteristics, Distributed Generation or Relay models. Load object may then refer to the Model Group
- Load Component
  - Special named object that contains a Characteristic
  - Then used inside the CompLoad characteristic
- Special Load Characteristic: CompLoad
  - New type of load characteristic model (like CIM5, IEEL, MOTORW, LDELEC, etc.)
  - This gives a combination of other load characteristics

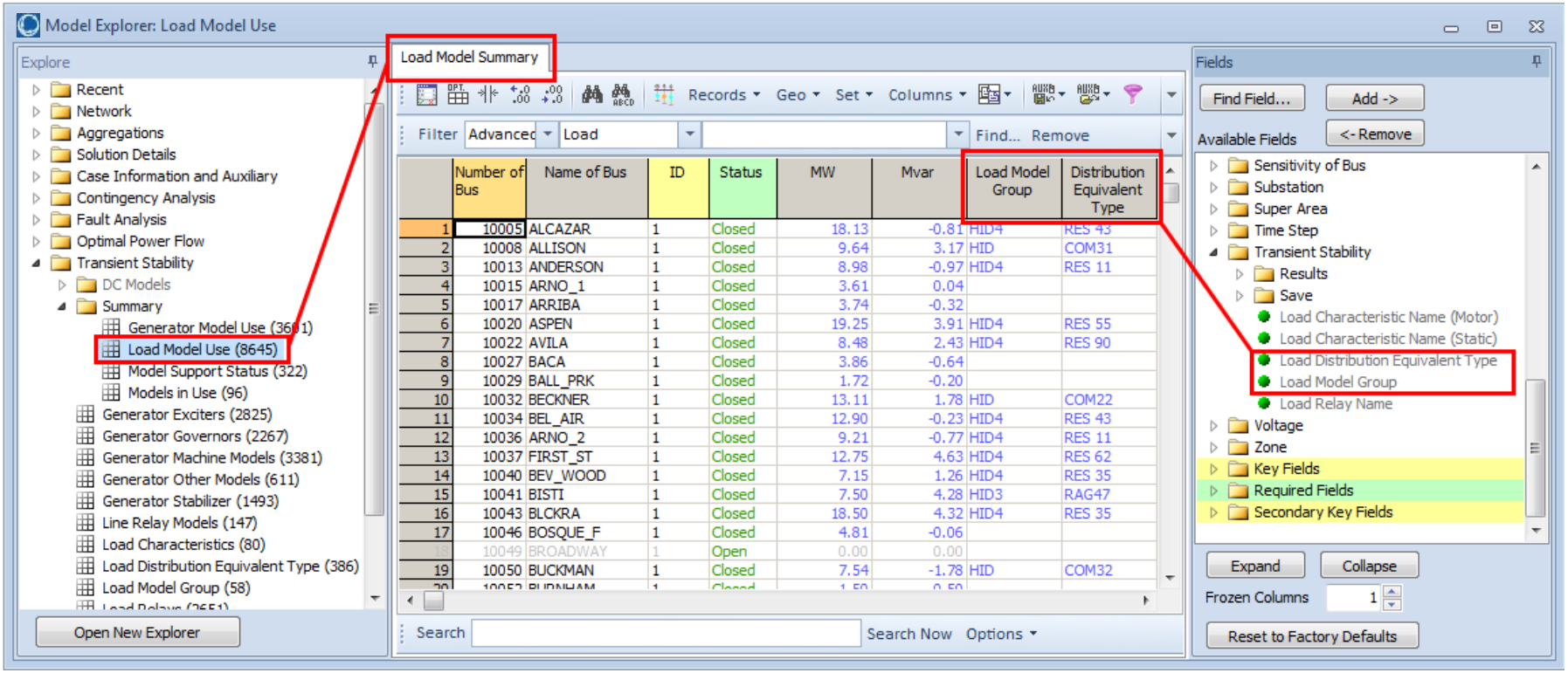
# Load Characteristic Models

- Load models apply to either a load, Load model group, bus, owner, zone, area, or the entire case

Precedence:
1.Load-specific
2.Load Model Group-specific
3.Bus-specific
4.Owner-specific
5.Zone-specific
6.Area-specific
7.System-specific
8.Default load modeling option with transient stability options



# Load Model Group
# Load Distribution Equivalent Type



# Load Model Group

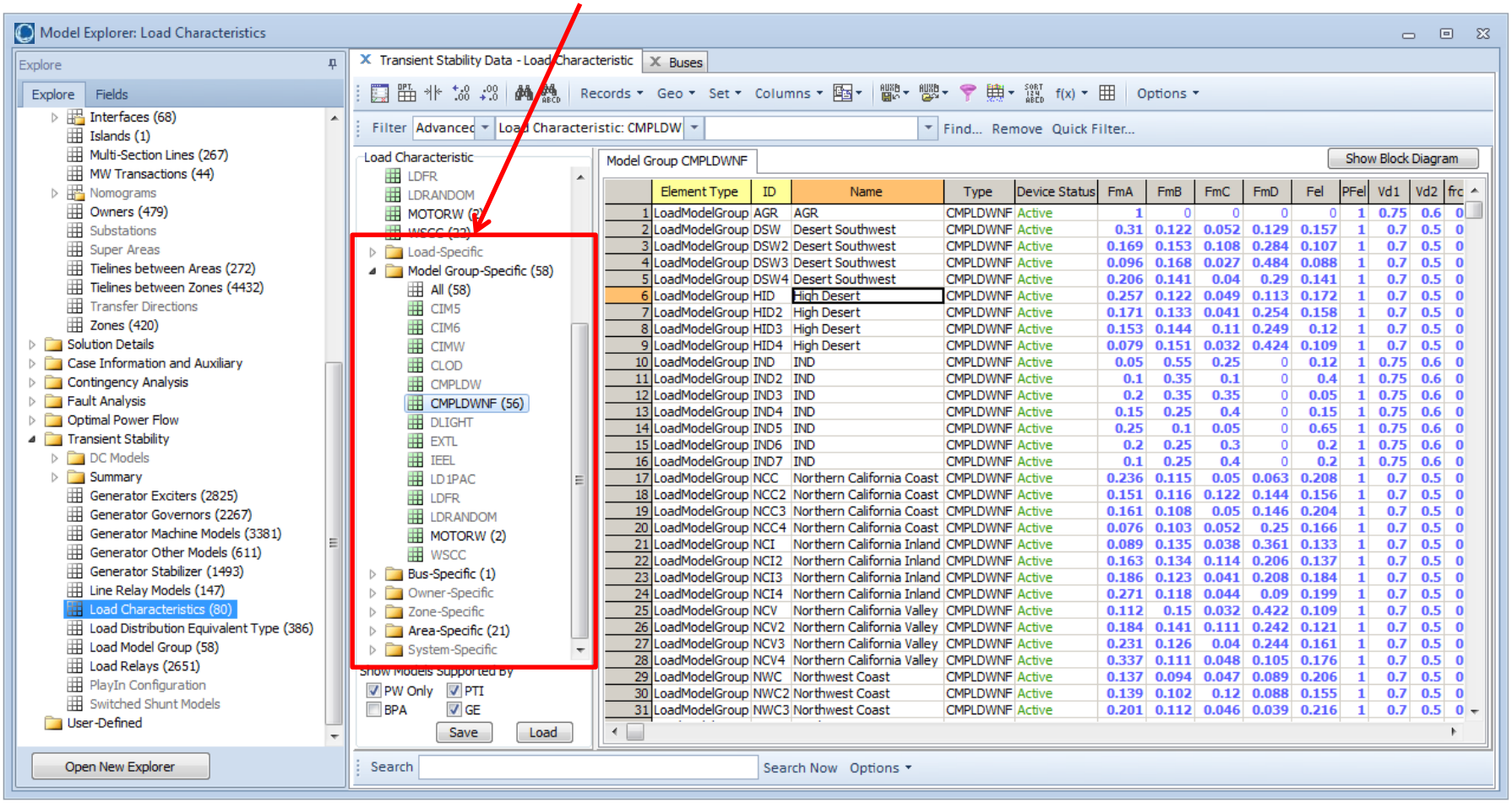
- Identified by unique name
- List of Load Characteristic Models assigned to it
  - CIM5, CIM6, MOTORW, WSCC, CMPLDWNF, etc.
- Allows flexibility in grouping load characteristic models with the same parameters
  - Useful when existing aggregations (such as area, zone, etc) don't capture this
  - *Climate-based* grouping such as "High Desert"
  - *Economic-based* grouping such as "Server Farm" or "Mining Operation"

# Load Characteristic Aggregate Models

- Load Characteristic used will be the model available at the lowest point in the precedence hierarchy as follows
  1. Load-specific
  2. Load Model Group-specific
  3. Bus-specific
  4. Owner-specific
  5. Zone-specific
  6. Area-specific
  7. System-specific
  8. Default load modeling option with transient stability options

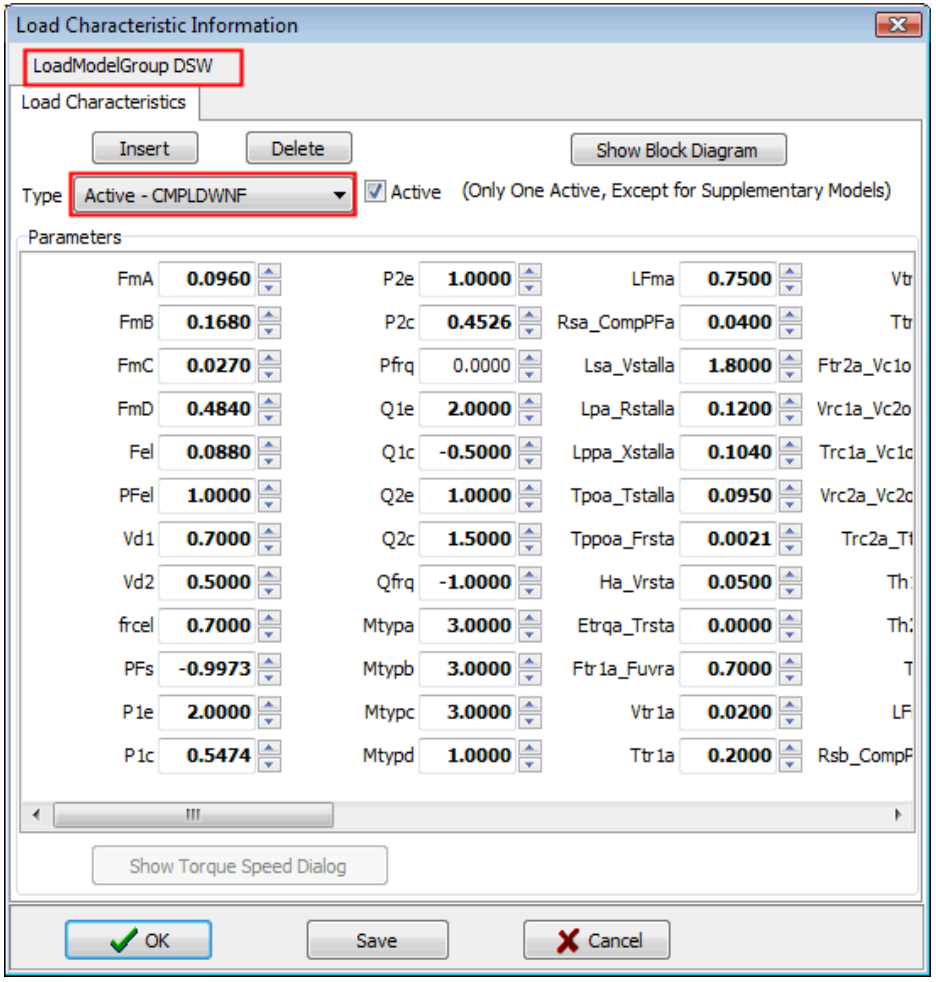
# Load Characteristic Models

## Load Model Hierarchy



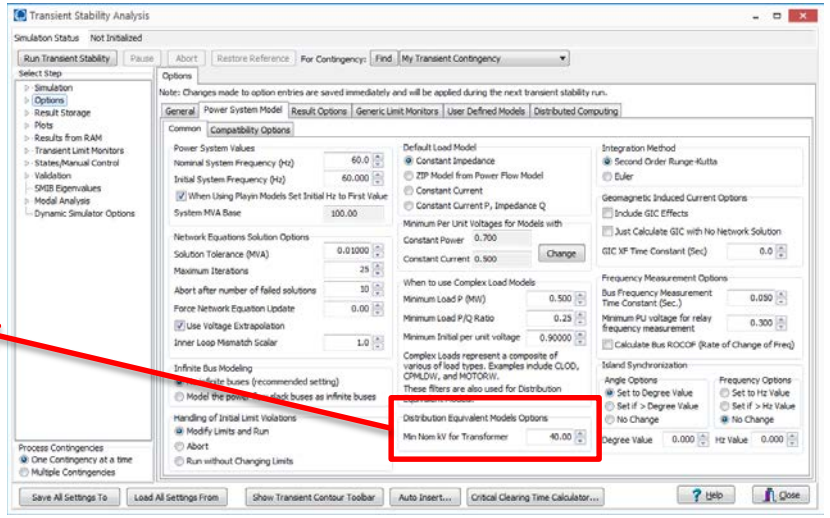
# Model CMPLDWNF

- Identical to CMPLDW except that parameters for Load Distribution Equivalent have been removed (first 17 parameters and MVABase)



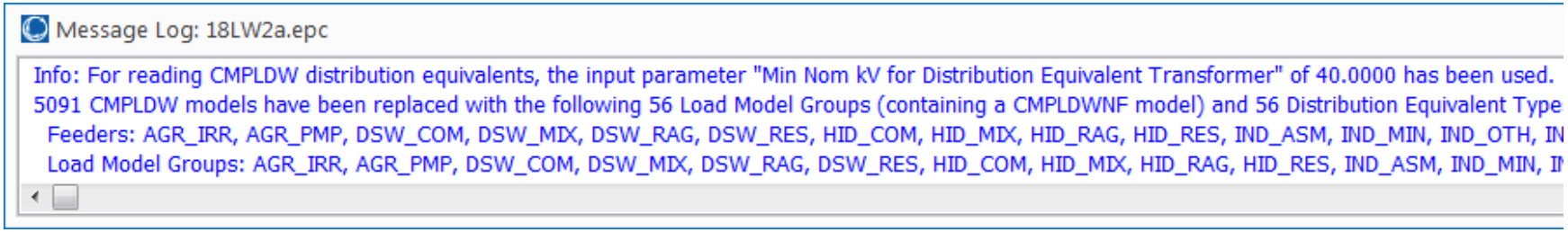
# New Option in Version 20

- Distribution Equivalent Models Options
  - Min Nom kV for Transformer: 40 kV is default
  - Any load connected to a bus with a nominal voltage below this will ignore the transformer impedance (Xxf) specified with the distribution

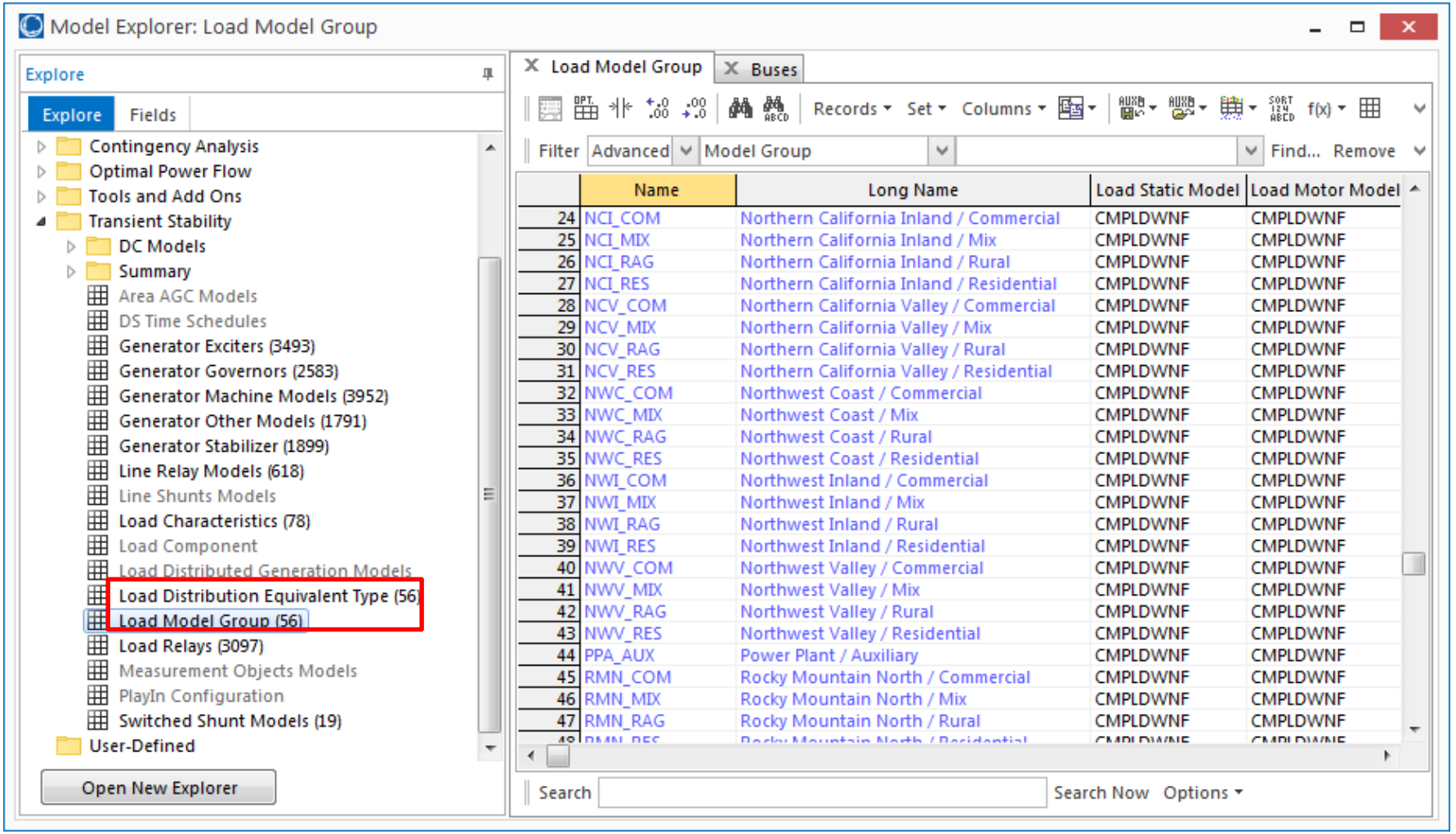


# What Happens When you open EPC and DYD files

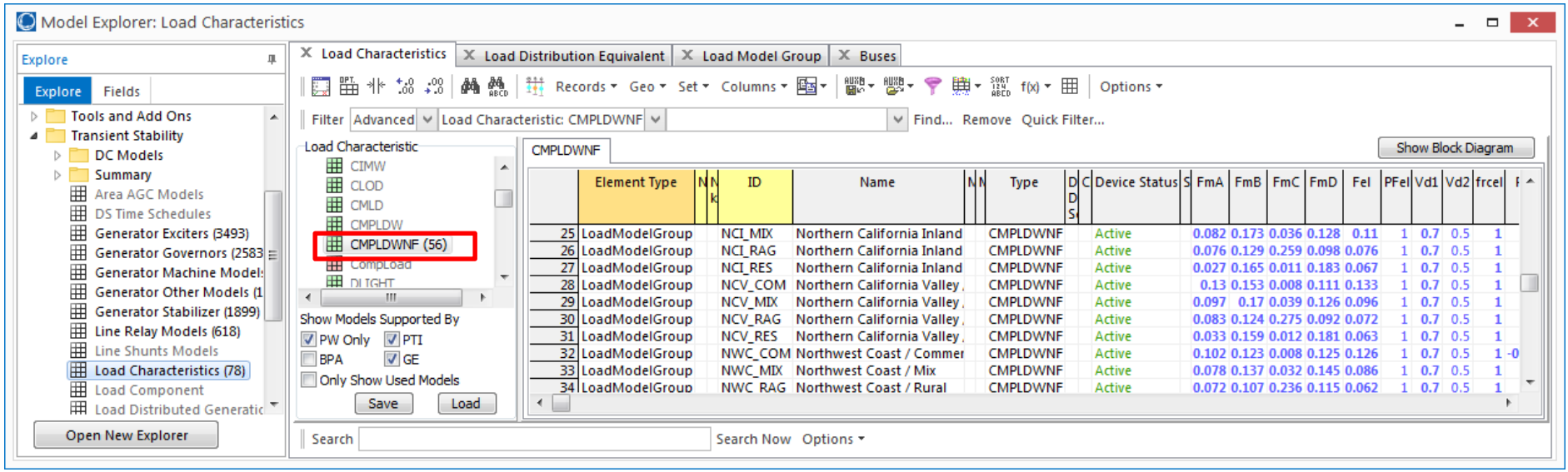
- Example: 18LW2a.epc and 18LW21.dyd
- Simulator groups together all CMPLDW records with same parameters
- Distribution Equivalents are created using first 17 parameters (and MVAbase) to create.
  - Each unique combination of these parameters
  - Try to use names from the load “long id” field
  - Also uses the new option in version 20 regarding the minimum Nom kV for Transformer
- LoadModelGroups are created using remaining values with each unique combination of these parameters
  - Try to use names from the load “long id” field



# 56 Load Model Groups

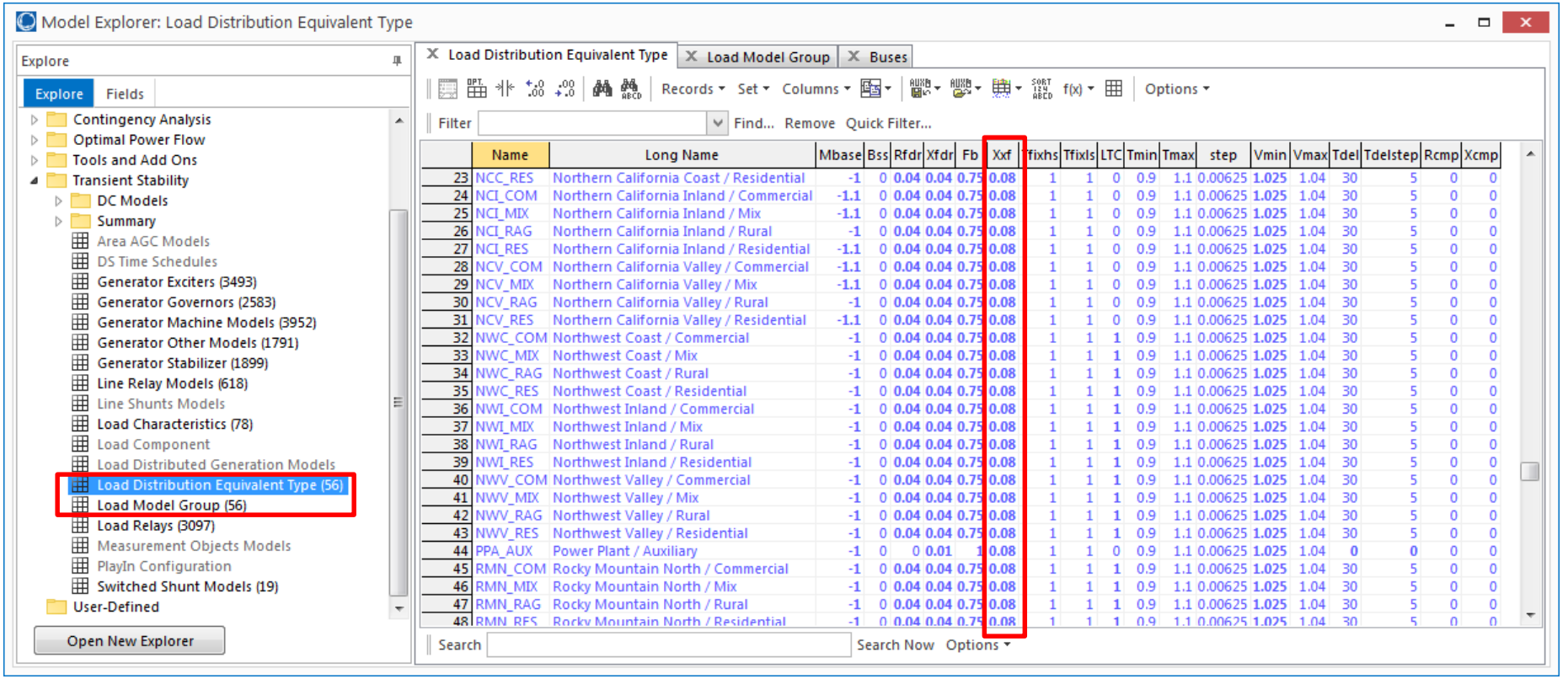


# 56 CMPLDWNF created (one for each LoadModelGroup)



# 56 Load Distribution Equivalents

- Note: All Xxf > 0 in example. This is because the option for 40 kV threshold handles ignoring Xxf when required




| | Name | Long Name | Mbase | Bss | Rfdr | Xfdr | Fb | Xxf | Tfixhs | Tfixls | LTC | Tmin | Tmax | step | Vmin | Vmax | Tdel | Tdelstep | Rcmp | Xcmp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | NCC_RES | Northern California Coast / Residential | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 24 | NCI_COM | Northern California Inland / Commercial | -1.1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 25 | NCI_MIX | Northern California Inland / Mix | -1.1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 26 | NCI_RAG | Northern California Inland / Rural | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 27 | NCI_RES | Northern California Inland / Residential | -1.1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 28 | NCV_COM | Northern California Valley / Commercial | -1.1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 29 | NCV_MIX | Northern California Valley / Mix | -1.1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 30 | NCV_RAG | Northern California Valley / Rural | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 31 | NCV_RES | Northern California Valley / Residential | -1.1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 32 | NWC_COM | Northwest Coast / Commercial | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 33 | NWC_MIX | Northwest Coast / Mix | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 34 | NWC_RAG | Northwest Coast / Rural | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 35 | NWC_RES | Northwest Coast / Residential | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 36 | NWI_COM | Northwest Inland / Commercial | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 37 | NWI_MIX | Northwest Inland / Mix | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 38 | NWI_RAG | Northwest Inland / Rural | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 39 | NWI_RES | Northwest Inland / Residential | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 40 | NWV_COM | Northwest Valley / Commercial | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 41 | NWV_MIX | Northwest Valley / Mix | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 42 | NWV_RAG | Northwest Valley / Rural | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 43 | NWV_RES | Northwest Valley / Residential | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 44 | PPA_AUX | Power Plant / Auxiliary | -1 | 0 | 0 | 0.01 | 1 | 0.08 | 1 | 1 | 0 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 0 | 0 | 0 | 0 |
| 45 | RMN_COM | Rocky Mountain North / Commercial | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 46 | RMN_MIX | Rocky Mountain North / Mix | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 47 | RMN_RAG | Rocky Mountain North / Rural | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |
| 48 | RMN_RES | Rocky Mountain North / Residential | -1 | 0 | 0.04 | 0.04 | 0.75 | 0.08 | 1 | 1 | 1 | 0.9 | 1.1 | 0.00625 | 1.025 | 1.04 | 30 | 5 | 0 | 0 |

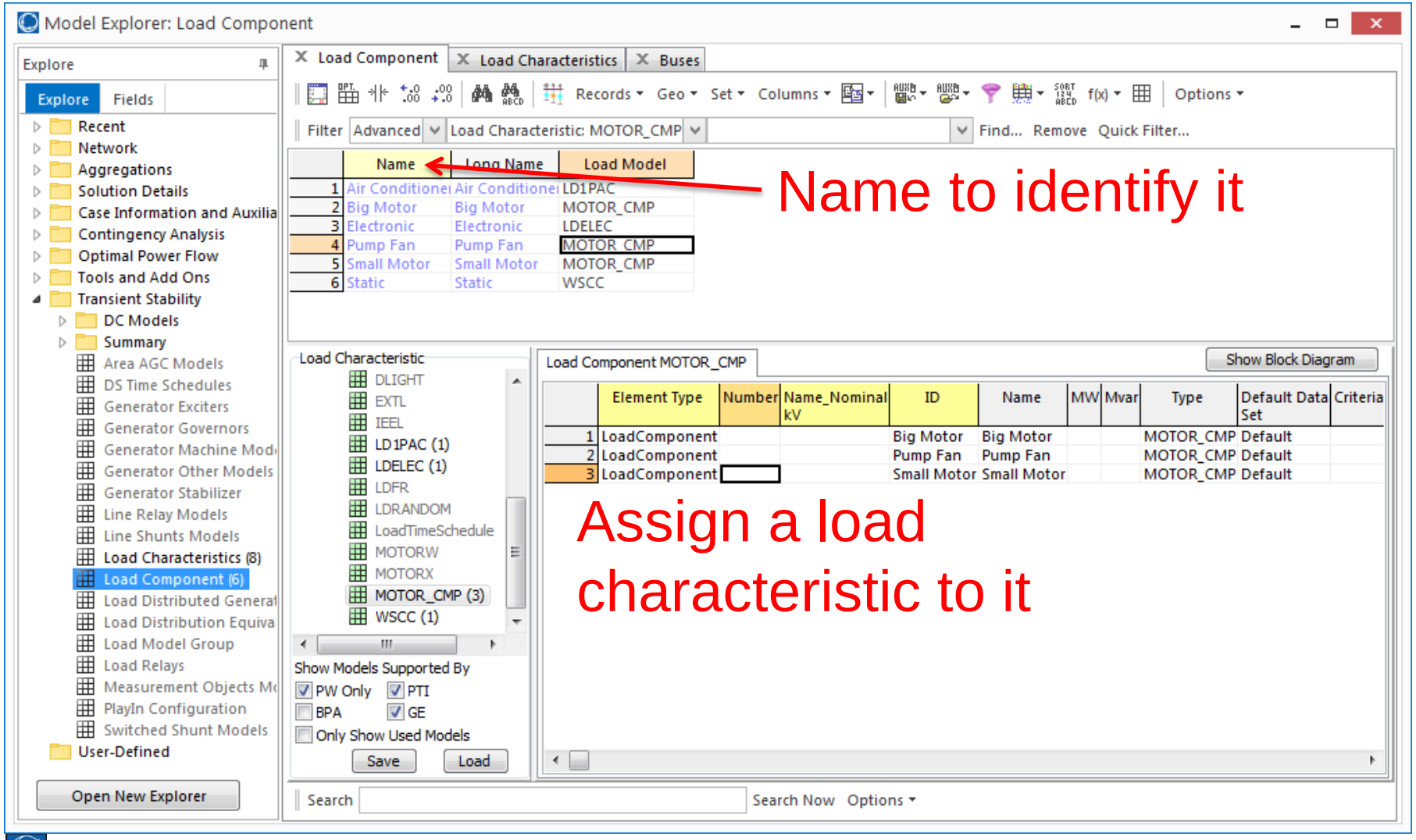
# Existing summary

- For data in existing cases, we think that managing 56 load characteristics and 56 distribution equivalents is manageable.
- Thus, CMPLDW works OK, but…
  - Model components *are fixed*
    - Always 4 motors (usually 3 induction motors and 1 single phase air conditioner)
    - 1 electronic load
    - 1 static load
  - This makes adding new pieces to the structure very cumbersome

# New in Version 20 of Simulator Available Summer 2017

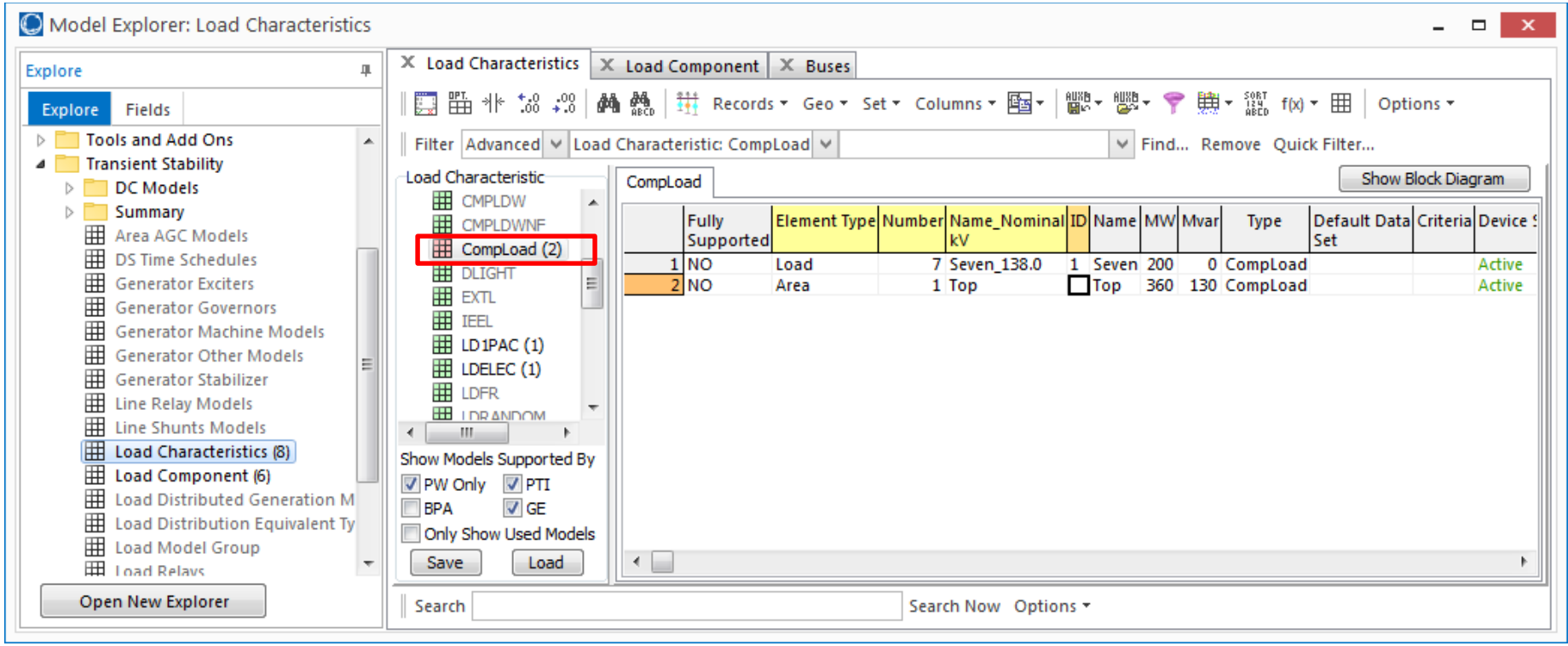
- Ability to make any combination of load characteristics
  - A new LoadComponent object
    - Name to identify it
    - Load characteristic assigned to it
  - Make a new type of load characteristic called CompLoad
    - Allow it to reference up to 10 LoadComponent objects along with assigning a fractions of each of those 10
- Most existing load characteristics can then be assigned to the LoadComponent
  - Benefit: As new stand-alone load characteristics are added to software, they are ***immediately*** available in the CompLoad structure

# New Object Record: LoadComponent



# New Load Characteristic: CompLoad

- CompLoad is a new type of load model
  - Just like other load characteristics (WSCC, MOTORW, CIM5, etc.)
  - Assign to a Load, LoadModelGroup, Bus, Area, Zone, Owner, or System

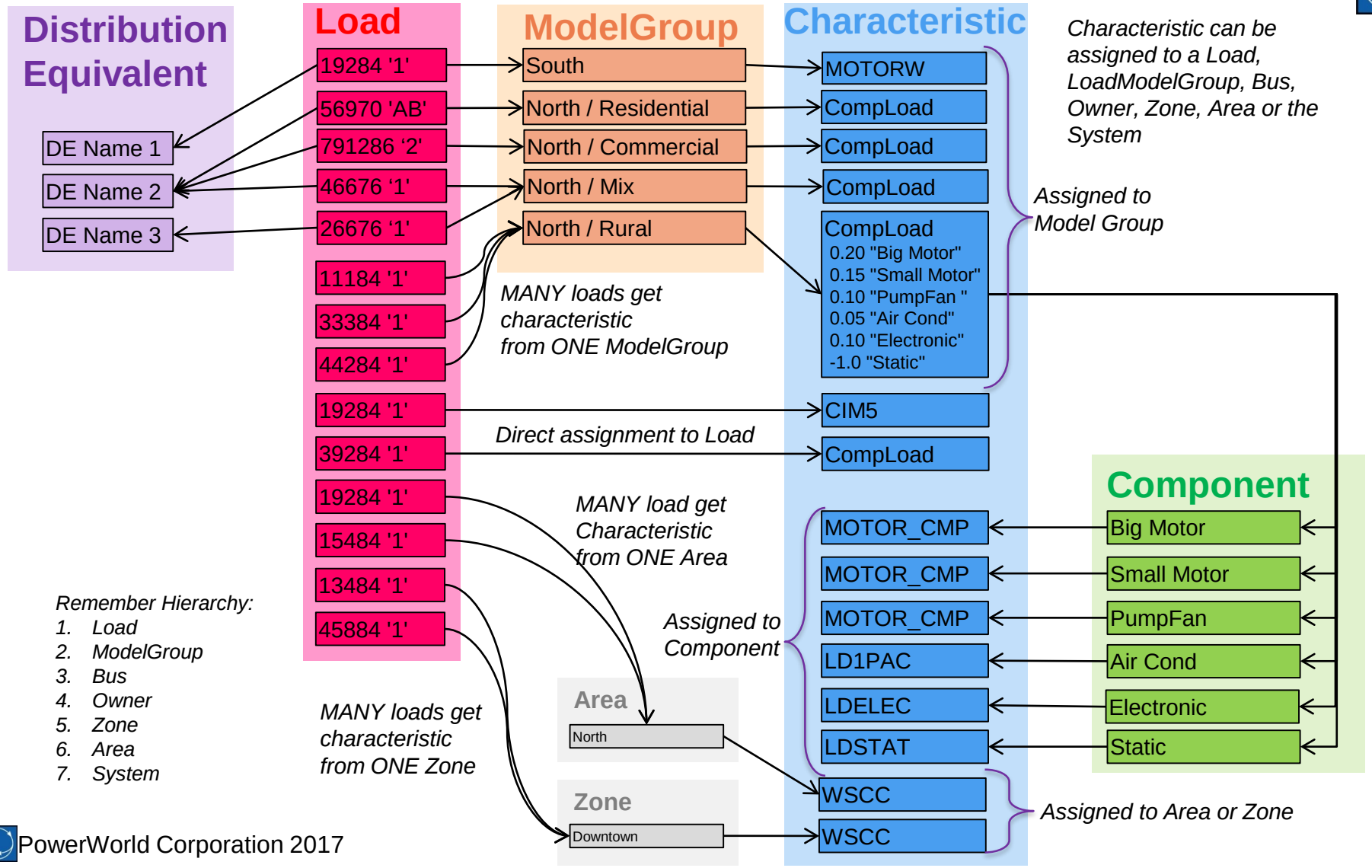


# Nomenclature Review

- Dynamic model structure for loads: 4 model types
  - Load Characteristic
    - Can be assigned in hierarchy levels (Load Model Group, Bus, Owner, Zone, Area, System)
  - Load Distribution Equivalent
    - Load object can be assigned to one
- Load Model Group
  - Load object can be assigned to one
- Load Component
  - Special named object that contains a Characteristic
  - Then used inside the CompLoad characteristic
- New Load Characteristic: CompLoad
  - New type of load characteristic model that gives a combination of other load characteristics

# Object References Picture

Shaded Regions represents data tables
Darker boxes inside tables represent one record of that table



# Restriction of Load Characteristics that can be assigned to a LoadComponent

- CompLoad only assigns *one percentage* to each LoadComponent it uses
  - This percentage applies to the total ***MW***
  - What about Mvar?
- Restriction for Load Characteristic: must automatically assign its Mvar based on the MW.
  - Induction Motor models already do this as does LD1PAC
  - Stand-alone model LDELEC has a new parameter (pfel)
  - Stand-alone model IEEL has a new parameter (Pfs)
  - (basically this is an issue for the algebraic load models!)
- Each component of the CompLoad will thus automatically determine its own Mvar value based on its own MW
  - Similar to existing motor models, the CompLoad will then include a capacitance to match the initial conditions for Mvar.

# What would happen with existing WECC data?

- New LoadComponent records would be created
  - 46 IEEL models that represent various combinations of ZIP models
  - 6 LD1PAC_CMP models.  Only difference is different Vstall values
  - 9 MOTOR_CMP models representing different combinations of three-phase motors
  - 3 LDELEC models represents slightly different Vd1/Vd2 values
- The 56 CMPLDWNF records assigned to LoadModelGroups would be replaced by 56 CompLoad  records instead

# Summary

- Modularize!
  - Following attributes of a load are not always related to one another.
  - Independent dynamic models should be used
    - Characteristic
    - Distributed Generation
    - Distribution Equivalent
    - Relays
- Aggregation Level Models
  - Load Model Group, Bus, Owner, Zone, Area, Case
- Named Load Components
  - CompLoad Characteristic represents a combination of other load model types