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
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 subtraction of the fields **Mvar – Dist Mvar**

<table>
<thead>
<tr>
<th>Number of Bus</th>
<th>Name of Bus</th>
<th>Area Name of Load</th>
<th>Zone Name of Load</th>
<th>ID</th>
<th>Status</th>
<th>MW</th>
<th>Mvar</th>
<th>MVA</th>
<th>S MW</th>
<th>S Mvar</th>
<th>Dist Status</th>
<th>Dist MW Input</th>
<th>Dist Mvar Input</th>
<th>Net Mvar</th>
<th>Net MW</th>
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<td>20.00</td>
<td>82.46</td>
<td>80.00</td>
<td>20.00</td>
<td>Closed</td>
<td>40.00</td>
<td>0.00</td>
<td>0.00</td>
<td>20.00</td>
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<tr>
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<td>Three</td>
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<td>30.00</td>
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<tr>
<td>4</td>
<td>Five</td>
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<td>1</td>
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<td>40.00</td>
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<td>40.00</td>
<td>Open</td>
<td>130.00</td>
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<td>0.00</td>
<td>40.00</td>
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<td>5</td>
<td>Six</td>
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<td>0.00</td>
<td>400.00</td>
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<td>0.00</td>
<td>Closed</td>
<td>200.00</td>
<td>0.00</td>
<td>0.00</td>
<td>200.00</td>
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<tr>
<td>6</td>
<td>Seven</td>
<td>Right</td>
<td>1</td>
<td>1</td>
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<td>400.00</td>
<td>0.00</td>
<td>400.00</td>
<td>400.00</td>
<td>0.00</td>
<td>Closed</td>
<td>200.00</td>
<td>0.00</td>
<td>0.00</td>
<td>200.00</td>
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</tbody>
</table>
Treatment of Distributed Generation in Power Flow

• Summary Information with Areas, Zones, Substations, etc...
  – Dist MW is separate summation from Load MW

<table>
<thead>
<tr>
<th>Area Num</th>
<th>Area Name</th>
<th>AGC Status</th>
<th>Gen MW</th>
<th>Load MW</th>
<th>Dist MW</th>
<th>Shunt MW</th>
<th>Tot Sched MW</th>
<th>Int MW</th>
<th>ACE MW</th>
<th>Lambda</th>
<th>Loss MW</th>
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<tr>
<td>1</td>
<td>Top</td>
<td>ED</td>
<td>367.42</td>
<td>720.00</td>
<td>120.000</td>
<td>0.00</td>
<td>-359.54</td>
<td>-359.54</td>
<td>0.00</td>
<td>0.48</td>
<td>6.96</td>
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<td>Left</td>
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<td>199.52</td>
<td>400.00</td>
<td>200.000</td>
<td>0.00</td>
<td>-200.82</td>
<td>-200.82</td>
<td>0.00</td>
<td>0.34</td>
<td>0.00</td>
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<tr>
<td>3</td>
<td>Right</td>
<td>ED</td>
<td>400.99</td>
<td>400.00</td>
<td>200.000</td>
<td>0.00</td>
<td>0.36</td>
<td>0.36</td>
<td>0.00</td>
<td>0.64</td>
<td>0.00</td>
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</tbody>
</table>

• 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

\[
\begin{align*}
Bf_1 &= (Fb)(Bf_1 + Bf_2) \\
Bf_2 &= (1-Fb)(Bf_1 + Bf_2)
\end{align*}
\]

Transformer Control
- LTC: Tmax, Tdel
- Tfixhs: Step, Tdelstep
- s: Vmin, Rcmp
- TfixIs: Vmax, Xcmp
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 \((X_{xf})\) 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 $X_{xf} > 0$ in example. This is because the option for 40 kV threshold handles ignoring $X_{xf}$ when required.
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
- 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

Name to identify it

Assign a load characteristic to it
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

Distribution Equivalent

<table>
<thead>
<tr>
<th>DE Name 1</th>
<th>DE Name 2</th>
<th>DE Name 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>19284 '1'</td>
<td>66970 'AB'</td>
<td>791286 '2'</td>
</tr>
<tr>
<td>46667 '1'</td>
<td>26667 '1'</td>
<td>11184 '1'</td>
</tr>
<tr>
<td>33384 '1'</td>
<td>44284 '1'</td>
<td>19284 '1'</td>
</tr>
<tr>
<td>39284 '1'</td>
<td>19284 '1'</td>
<td>15484 '1'</td>
</tr>
<tr>
<td>13484 '1'</td>
<td>45884 '1'</td>
<td>11184 '1'</td>
</tr>
</tbody>
</table>

Load

<table>
<thead>
<tr>
<th>Load</th>
<th>ModelGroup</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>19284 '1'</td>
<td>South</td>
<td>MOTORW</td>
</tr>
<tr>
<td>66970 'AB'</td>
<td>North / Residential</td>
<td>CompLoad</td>
</tr>
<tr>
<td>791286 '2'</td>
<td>North / Commercial</td>
<td>CompLoad</td>
</tr>
<tr>
<td>46667 '1'</td>
<td>North / Mix</td>
<td>CompLoad</td>
</tr>
<tr>
<td>26667 '1'</td>
<td>North / Rural</td>
<td>CompLoad</td>
</tr>
<tr>
<td>11184 '1'</td>
<td></td>
<td>CompLoad</td>
</tr>
<tr>
<td>33384 '1'</td>
<td></td>
<td>CIM5</td>
</tr>
<tr>
<td>44284 '1'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19284 '1'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39284 '1'</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ModelGroup

<table>
<thead>
<tr>
<th>ModelGroup</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>North / Residential</td>
<td>MOTORW</td>
</tr>
<tr>
<td>North / Commercial</td>
<td>CompLoad</td>
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<td>North / Mix</td>
<td>CompLoad</td>
</tr>
<tr>
<td>North / Rural</td>
<td>CompLoad</td>
</tr>
<tr>
<td>South</td>
<td>CompLoad</td>
</tr>
</tbody>
</table>

Characteristics

- MANY loads get characteristic from ONE ModelGroup
- Direct assignment to Load
- MANY load get Characteristic from ONE Area
- MANY loads get characteristic from ONE Zone

Remember Hierarchy:
1. Load
2. ModelGroup
3. Bus
4. Owner
5. Zone
6. Area
7. System

Component

<table>
<thead>
<tr>
<th>Component</th>
<th>Assigned to Area or Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Motor</td>
<td></td>
</tr>
<tr>
<td>Small Motor</td>
<td></td>
</tr>
<tr>
<td>PumpFan</td>
<td></td>
</tr>
<tr>
<td>Air Cond</td>
<td></td>
</tr>
<tr>
<td>Electronic</td>
<td></td>
</tr>
<tr>
<td>Static</td>
<td></td>
</tr>
</tbody>
</table>

Characteristic can be assigned to a Load, LoadModelGroup, Bus, Owner, Zone, Area or the System

Assigned to Model Group

Assigned to Area or Zone

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