ELECTRIC DISTRIBUTION SYSTEMS

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September 26, 2014

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Voltages

- Primary:
  - 4kV to 34.5kV
  - For industrial customers
  - Three phase
- Secondary:
  - 120/240V
  - Residential/commercial customers
  - Single phase

Components

- Substations—facility that acts as junctions in the distribution system
- Distribution Feeder Circuits—connects substation output to primary circuits
- Protective Equipment
  - Relays, Fuses, Disconnect Switches, etc
- Primary Circuits—circuit that carry power from substation to load area
- Distribution Transformers—device that alters voltage level
- Secondaries—three one phase lines extending from distribution transformers
- Services—the wires extending from secondaries to load

Components

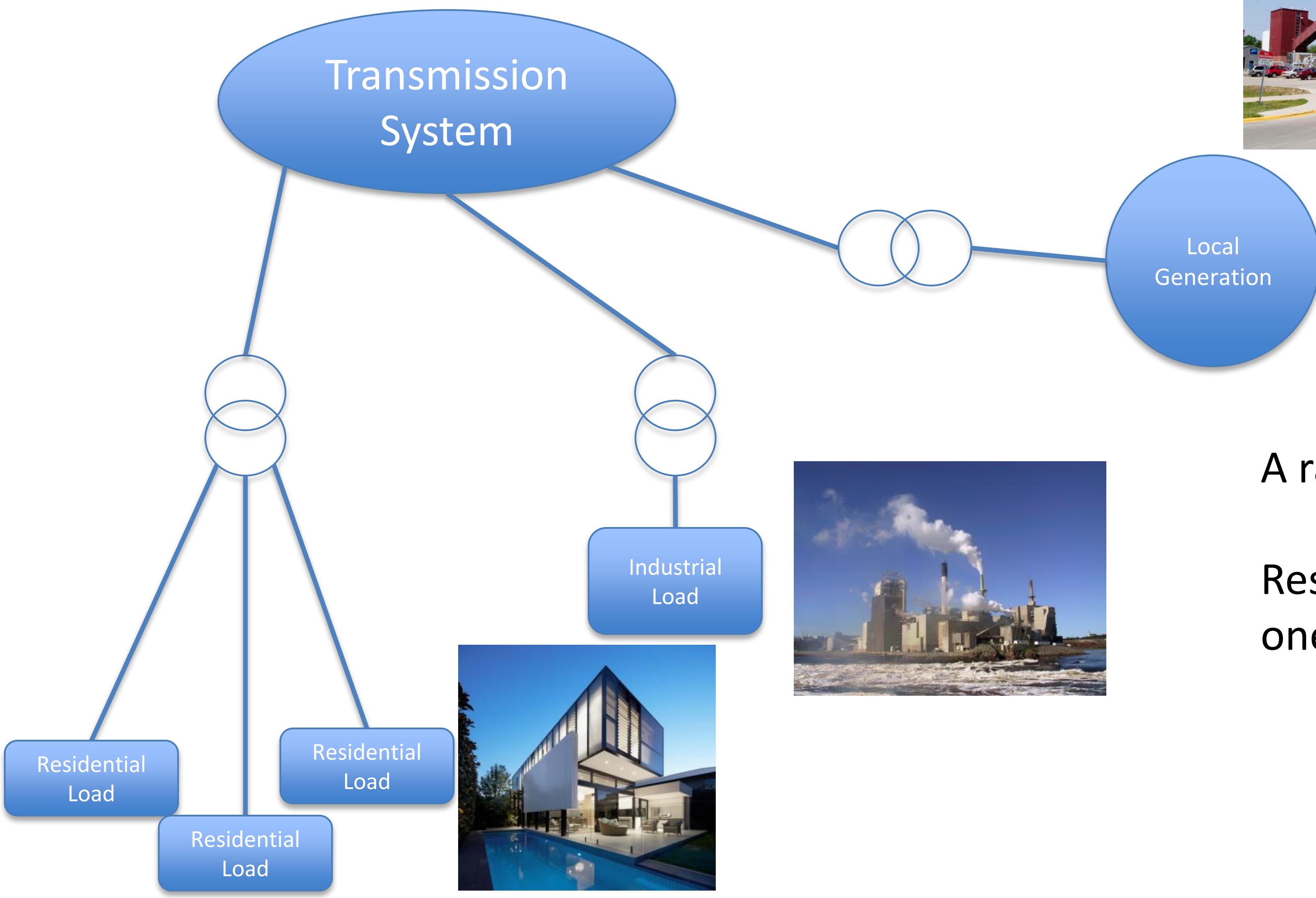
Image Credit: United States Department of Labor
https://www.osha.gov/SLTC/etools/electric_power/illustrated_glossary/distribution_system.html

Advanced Components:
Advanced Metering Infrastructure (AMI)

Smart Meter

Image Credit: http://emfsafetynetwork.org/wp-content/uploads/2011/03/DSC_0097.jpg

Network Topology



A radial system

Residential load exist on one phase each

Modeling Distribution Systems

- Similar to transmission modeling, but with more detail.
- Loads are unbalanced on a distribution system.
- Single and double phase lines exist.
- The R/X values of a distribution system are much higher.
  - This necessitates the use of powerflow algorithms that are different from those used in transmission modeling.

GridLAB-D

- Open source software
- For Power System Modeling and Simulation
- Developed by Pacific Northwest National Laboratory
- Funded by the U.S. Department of Energy

What is unique about GridLAB-D?

- Provides a taxonomy of **distribution feeder models** that are representative of those operating in the U.S.
- Accurately models end-use loads using a **multi-disciplinary approach** (vs treating them as ZIP loads). Eg: Waterheater
- Focus on **distribution network** (vs transmission).
- Accurately models the **physical properties** of power distribution infrastructure. Eg: Line spacing, Overhead/Underground lines, Transformer connections (3 phase and split-phase), etc.

Distribution Feeder Taxonomy

- 575 distribution feeder models were collected from utilities across the U.S. from the different climatic regions

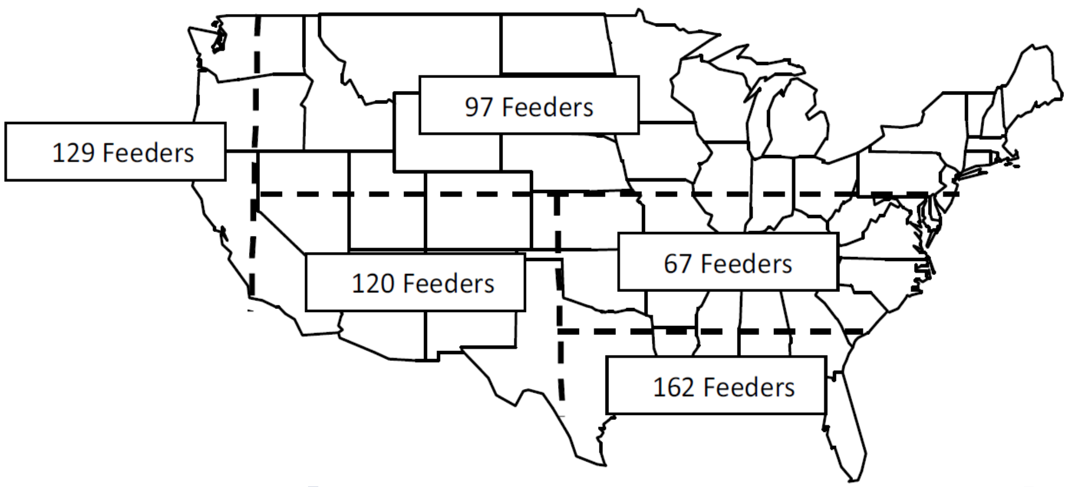


Figure 2: Feeder locations and climate regions of the United States

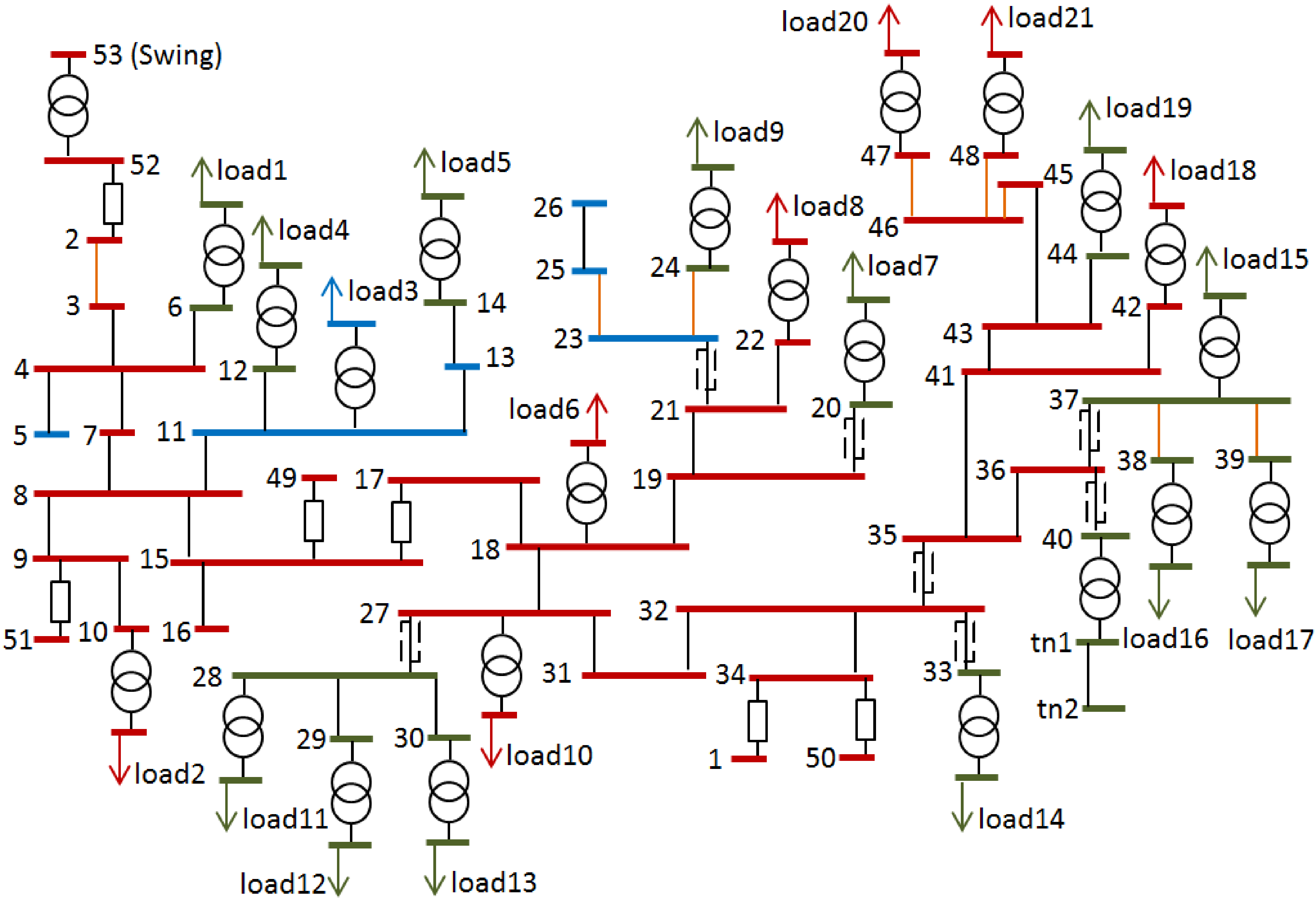
- 24 representative prototypes were developed

Distribution Feeder Taxonomy (2)

- “Represents the first collection of models that is openly available and presented in the level of detail that is necessary to evaluate the effects of smart grid technologies.”
- Models are all available only in GridLAB format (resembling C++ class syntax).

```
object overhead_line_conductor {
        name OH100;
        geometric_mean_radius 0.0244;
        resistance 0.306;
}

object overhead_line_conductor {
        name OH101;
        geometric_mean_radius 0.00814;
        resistance 0.592;
}

object line_spacing {
        name LS200;
        distance_AB 2.5;
        distance_BC 4.5;
        distance_AC 7.0;
        distance_AN 5.656854;
        distance_BN 4.272002;
        distance_CN 5.0;
}

object line_configuration {
        name LC300;
        conductor_A OH100;
        conductor_B OH100;
        conductor_C OH100;
        conductor_N OH101;
        spacing LS200;
}
```

```
object transformer_configuration {
        name XFC400;
        connect_type 2;
        power_rating 6000;
        primary_voltage 12470;
        secondary_voltage 4160;
        resistance 0.01;
        reactance 0.06;
}

object transformer_configuration {
        name PoleTop;
        connect_type SINGLE_PHASE_CENTER_TAPPED;
        power_rating 400;
        powerA_rating 400;
        primary_voltage 2400;
        secondary_voltage 120;
        resistance 0.01;
        reactance 0.06;
}

object node {
        name Node1;
        phases A|B|C;
        voltage_A +7199.558+0.000j;
        voltage_B -3599.779-6235.000j;
        voltage_C -3599.779+6235.000j;
        nominal_voltage 7199.558;
}

object overhead_line {
        name Link12;
        phases A|B|C;
        from Node1;
        to Node2;
        length 2000;
        configuration LC300;
```


53 (Swing)
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51
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tn2
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load2
load3
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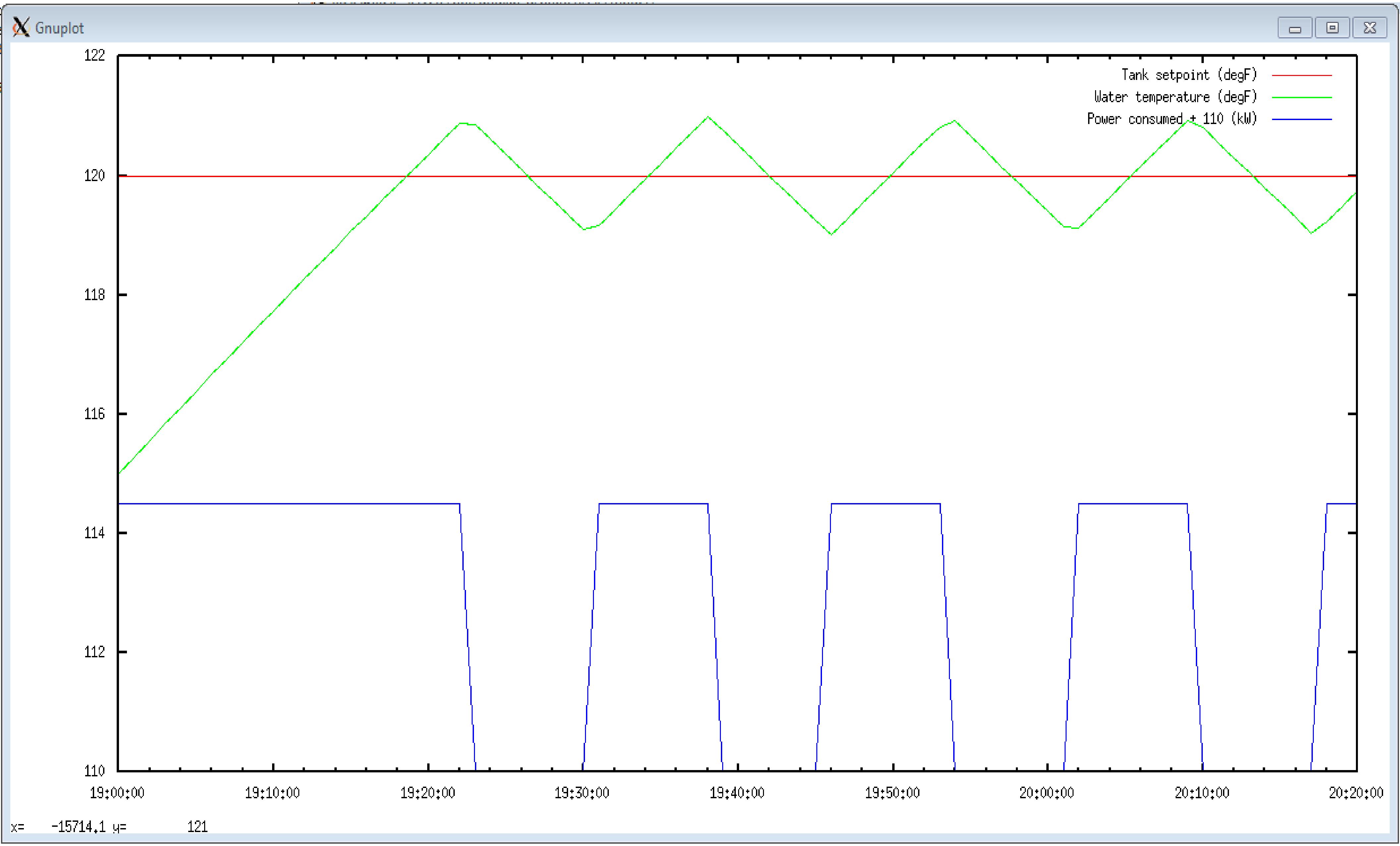
load20
load21

Thermostatically controlled loads

Waterheater Properties

Property Name	Type	Unit	Description
tank_volume	double	gallons	The water volume of the water tank.
tank_UA	double	BTU/hour	The product of the U-value of the tank's insulation and the surface area of the tank, assuming R values of about 13.
tank_diameter	double	feet	The diameter of the water tank, influences heat loss calculations.
water_demand	double	gallons/minute	Hot water consumption. Constant unless controlled by a Player object.
heating_element_capacity	double	Watts	The rate at which the waterheater heating element will dump thermal energy into the water tank.
inlet_water_temperature	double	degF	The temperature of the cold water entering the bottom of the waterheater to replace any hot water drawn out the top of the tank.
heat_mode	enumeration		"ELECTRIC" or "GASHEAT". Determines the method that heat is added to the water tank.
location	enumeration		"INSIDE" or "GARAGE". Placement determines if thermal losses from the water heater wind up heating up the house, and if the outside temperature influences the effective temperature for heat loss.
tank_setpoint	double	degF	The target temperature at which the heating elements will click on and off in the waterheater.
thermostat_deadband	double	degF	The number of degrees to heat the water when needed. Influences when the water heating element will turn on and turn off.
meter	double	kilowatt-hours	The total power consumed by the water heater during the simulation.
temperature	double	degF	The temperature of the hot water in the tank.
height	double	feet	The height of the hot water tank.
enduse_load	complex	kilowatts	The current power draw of the water heater. Required by the house to attach the water heater to the circuit panel.
constant_power	complex	kilowatts	The constant power draw of the water heater. No effect ~ modify the heating_element_capacity.
constant_current	complex	amps	The constant current draw of the water heater. No effect.
constant_admittance	complex	1/Ohm	The constant admittance of power across the water heater. No effect.
internal_gains	double	kilowatts	The heat loss for the current timestep from the water heater to the water tank's location.


Gnuplot
Tank setpoint (degF)
Water temperature (degF)
Power consumed + 110 (kW)
122
120
118
116
114
112
110
19:00:00
19:10:00
19:20:00
19:30:00
19:40:00
19:50:00
20:00:00
20:10:00
20:20:00
x= -15714.1 y= 121