GRIDWORKS

ENHANCING GRIDLAB-D: LAUNCH WORKSHOP

IN-PERSON WORKSHOP

SEPTEMBER 6TH, 2018

1111 BROADWAY, OAKLAND CA

Agenda

Agenda:

10:15 Welcome/Introductions

10:30 Session 1: Tom McDermott (DOE) – Overview of DOE GridLAB-D Projects (Helics, TESP, GridAPPS-D)

11:30 Session 2: David Chassin (SLAC) – Growing GridLAB-D through California's EPIC Projects (Powernet, OpenFIDO, HIPAS, Glow)

12:30 Lunch Break

1:30 Session 3: Pedram Jahangiri (National Grid) – Case Study: National Grid's Use of GridLAB-D

2:30 Session 4: Matthew Tisdale (Gridworks) – GridLAB-D's Place in California's Clean Energy Landscape

3:30: Open Discussion

16:00 Adjourn

Introduction and Purpose

Roll call

Current DOE Projects Related to GridLAB-D at PNNL

1. **Transactive Energy Simulation Platform (TESP)**
2. **Co-simulation with HELICS and Jmodelica**
3. **GridAPPS-D^{TM} Application Development Platform**
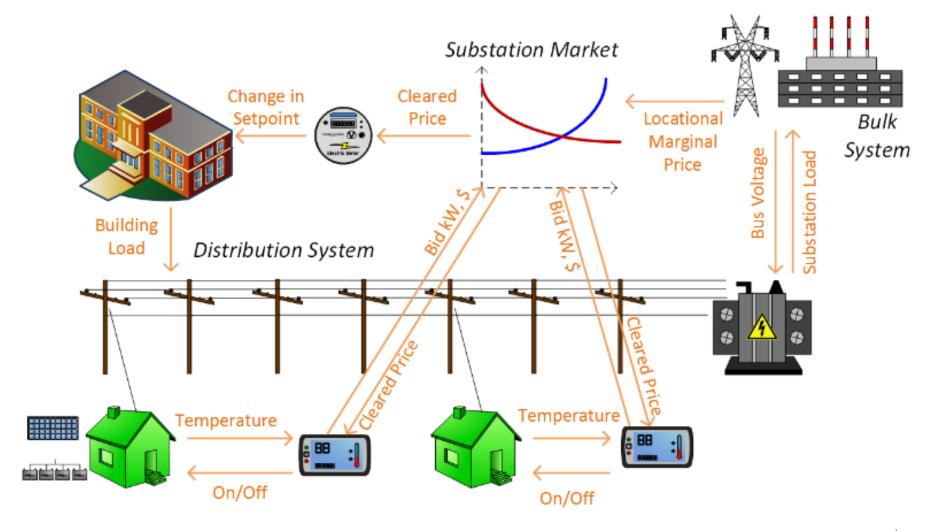4. **The Common Information Model (IEC 61968/61970)**

THOMAS E. MCDERMOTT, Ph.D., PE, FIEEE

Chief Engineer, Integration Team, Electricity Infrastructure

Pacific Northwest National Laboratory

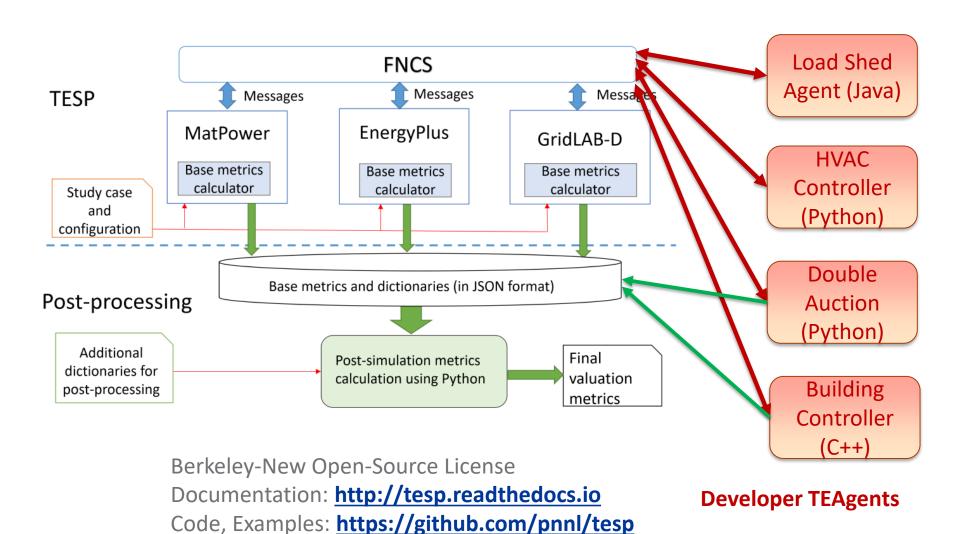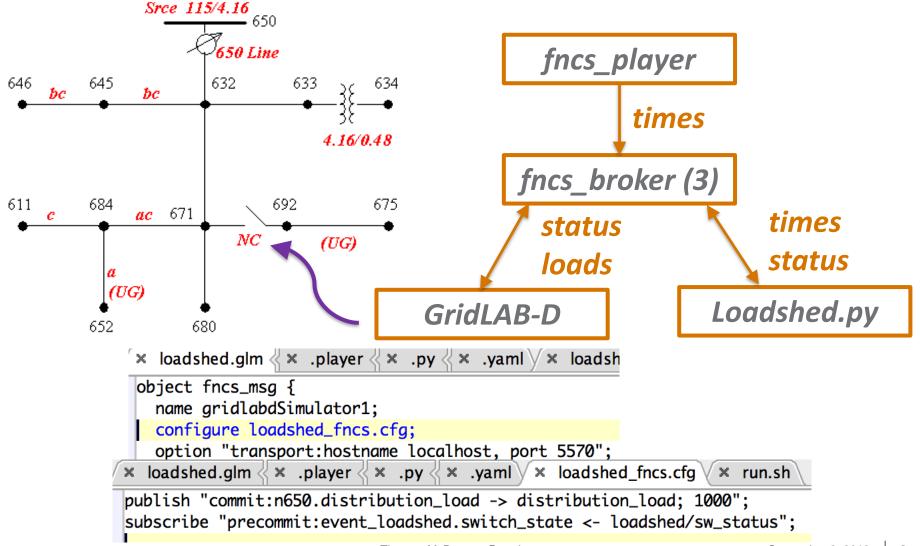# Open-source TESP federates domain simulators with custom valuation and transactive agents (TEAgents).

Berkeley-New Open-Source License
Documentation: **http://tesp.readthedocs.io**
Code, Examples: **https://github.com/pnnl/tesp**

Developer TEAgents

A controllable switch was added to GridLAB-D for load shedding over FNCS

Srce 115/4.16
650
650 Line
646   645   632   633   634
  bc   bc   4.16/0.48
611   684   671   692   675
  c   ac   NC   (UG)
       a
      (UG)
652   680

fncs_player

times

fncs_broker (3)

status
loads

times
status

GridLAB-D

Loadshed.py

```
× loadshed.glm  × .player  × .py  × .yaml  × loadsh

object fncs_msg {
  name gridlabdSimulator1;
  configure loadshed_fncs.cfg;
  option "transport:hostname localhost, port 5570";

× loadshed.glm  × .player  × .py  × .yaml  × loadshed_fncs.cfg  × run.sh

publish "commit:n650.distribution_load -> distribution_load; 1000";
subscribe "precommit:event_loadshed.switch_state <- loadshed/sw_status";
```

Software agents can be written in Python, C/C++ or Java.

```
(export FNCS_LOG_STDOUT=yes && exec fncs_broker 3 &> broker.log &)
(exec gridlabd loadshed.glm &> gridlabd.log &)
(exec fncs_player 6h loadshed.player &> player.log &)
(export FNCS_CONFIG_FILE=loadshed.yaml && exec python loadshed.py 21600 &> loadshed.log &)
```

FNCS Configuration in loadshed.yaml File:
this one subscribes to one (scripted) value

```
× loadshed.py   × .yaml
name: loadshed
time_delta: 1s
broker: tcp://localhost:5570
values:
    sw_status:
        topic: player/sw_status
        default: 1
```

```
× loadshed.player   × .py   × .yaml
#time    topic          value
0    sw_status      1
1800000000000        sw_status    0
5400000000000        sw_status    1
16200000000000       sw_status    0
19800000000000       sw_status    1
21600000000000       sw_status          1
```
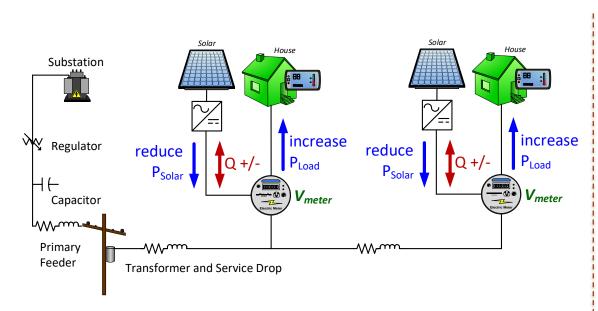
```python
× loadshed.py   × .yaml
import string;
import sys;
import fncs;

time_stop = int(sys.argv[1])
time_granted = 0

# requires yaml specificied in an envar
fncs.initialize()

while time_granted < time_stop:
    time_granted = fncs.time_request(time_stop)
    events = fncs.get_events()
    for key in events:
        topic = key.decode()
        print (time_granted, key, topic,
               fncs.get_value(key), flush=True)
        value = fncs.get_value(key).decode()
        if topic == 'sw_status':
            fncs.publish('sw_status', value)

fncs.finalize()
```

In the NIST TE Challenge 2 project, we explored transactive approaches to mitigating voltage violations.
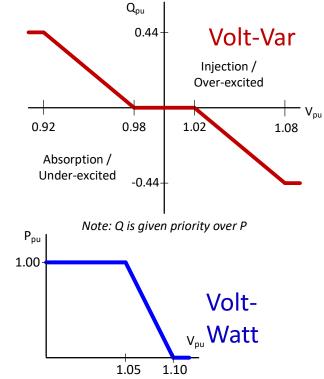
Pre-cooling option turns down the thermostat 4 degrees in response to an overvoltage.

Smart Inverters

Volt-Var

Injection / Over-excited

Absorption / Under-excited

Note: Q is given priority over P

Volt-Watt
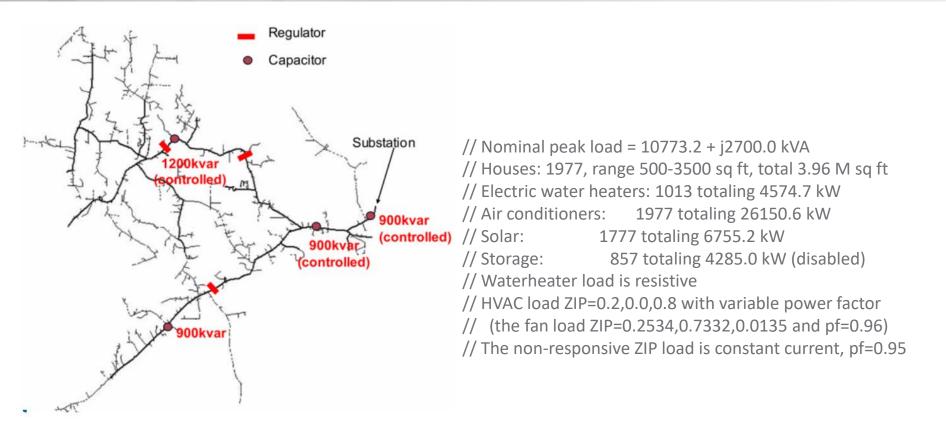
IEEE 8500-node feeder is realistic, set up for high-penetration PV and voltage issues

Regulator

Capacitor

1200kvar
(controlled)

900kvar
(controlled)

900kvar
(controlled)

900kvar

Substation

```
// Nominal peak load = 10773.2 + j2700.0 kVA
// Houses: 1977, range 500-3500 sq ft, total 3.96 M sq ft
// Electric water heaters: 1013 totaling 4574.7 kW
// Air conditioners:     1977 totaling 26150.6 kW
// Solar:             1777 totaling 6755.2 kW
// Storage:           857 totaling 4285.0 kW (disabled)
// Waterheater load is resistive
// HVAC load ZIP=0.2,0.0,0.8 with variable power factor
//   (the fan load ZIP=0.2534,0.7332,0.0135 and pf=0.96)
// The non-responsive ZIP load is constant current, pf=0.95
```
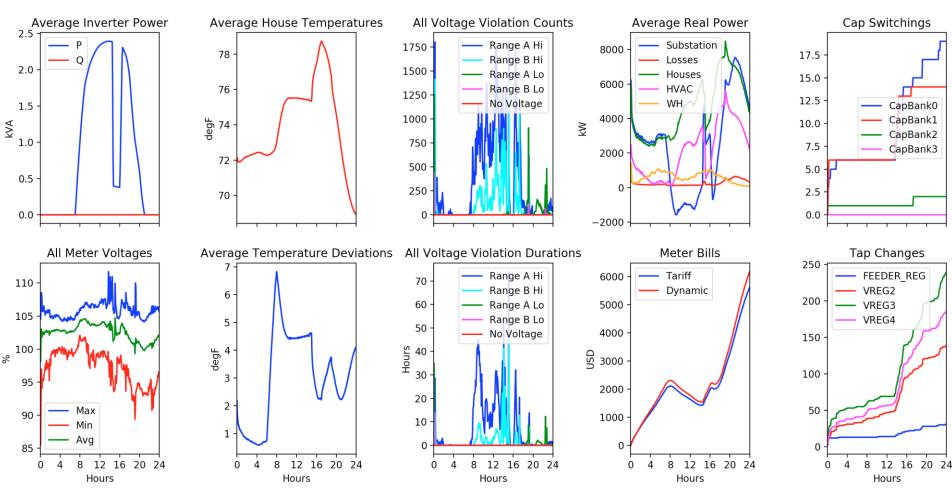
R. F. Arritt and R. C. Dugan, "The IEEE 8500-node test feeder", 2010 IEEE PES T&D
http://sites.ieee.org/pes-tccwg/links-to-test-cases/
https://github.com/pnnl/tesp/tree/master/examples/ieee8500

Pre-cooling offset of 4°F locked in all day to avoid oscillations, increased the bill by 11%.

After 4 a.m.: 464 Hours > B Range Voltage, 3.46 ºF Mean Deviation from Set-point,
22 Capacitor Switching Operations, 460 Tap Changes
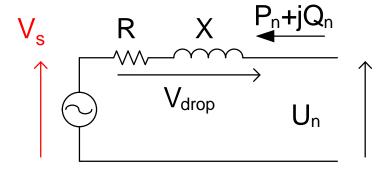
Estimating % Voltage Change:

I_{fault} = 2865 A @ 112.14 V (0.935 pu)

R + jX = 0.0318 + j0.02082 Ω

U_n = 0.12 kV, P_n = 0.007 MW, Q_n = 0.44P_n

(note: X/R = 0.6547)

V_s

R   X $P_n + jQ_n$

V_{drop}

U_n

$$V_{drop} = \frac{100}{U_n^2}(R_1 + jX_1)(P_n - jQ_n)$$

$$\frac{dV}{U_n} = \sqrt{(100 - \mathrm{Re}\,V_{drop})^2 + (\mathrm{Im}\,V_{drop})^2} - 100$$

(R, X in Ω, S_n in MVA, U_n in kV)

Voltage Change vs. Power Injected

The Volt-Var function is more aggressive and persistent than Volt-Watt because more inverters participate.

Volt-Var, 3 kW Inverter

Volt-Watt, 5 kW Inverter
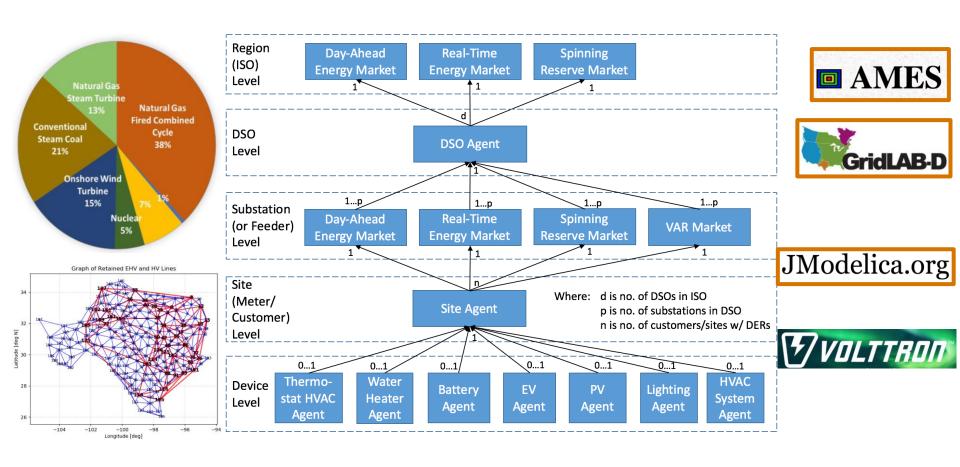
Selected Inverters have the longest duration above 1.05 pu voltage for each case, on the IEEE 8500-node test feeder.

Many new types of DER agents are under development for a transactive DSO study, set in Texas.

AMES

GridLAB-D

JModelica.org

VOLTTRON

Where: d is no. of DSOs in ISO
p is no. of substations in DSO
n is no. of customers/sites w/ DERs

Project Description
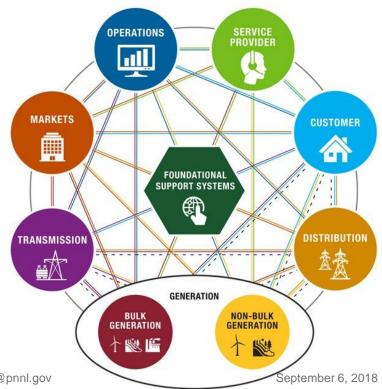
This project aims to enable large-scale TDC interdependency studies through a flexible and scalable, open-source co-simulation platform for the following industry drivers

Value Proposition

✓ There is currently a gap in simulation and modeling technology that inhibits integrated planning across multiple domains

✓ Left to it's own devices, the grid community is unlikely to develop capabilities to overcome planning stovepipes (in near term)

✓ The DOE plays a unique role in initiating this effort and creating foundational tools that support both research and industry

Project Objectives

✓ Provide foundational capabilities for grid planning, operation, and control

✓ Engage and educate grid developers on the value of multi-domain planning

Image from smartgrid.ieee.org
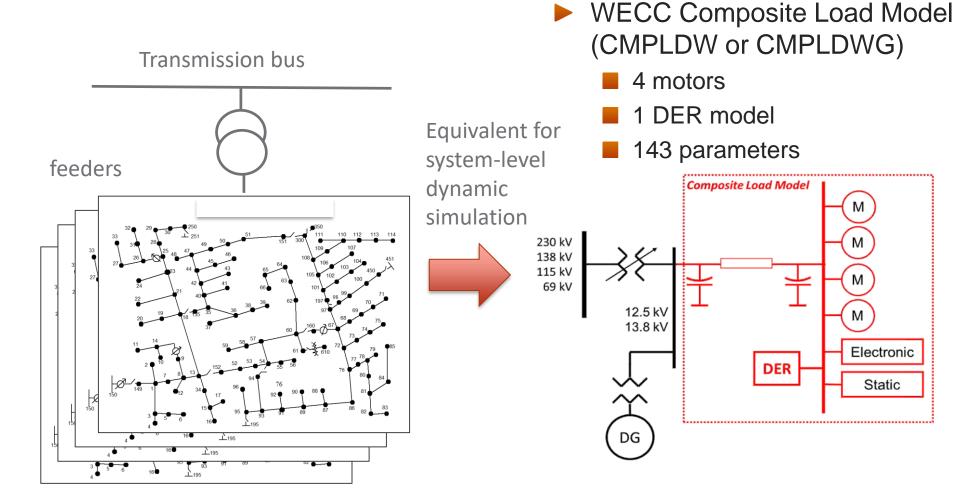
HELICS Layered Design

HELICS use case for validating a composite load model.

Transmission bus

feeders

Equivalent for system-level dynamic simulation

▶ WECC Composite Load Model (CMPLDW or CMPLDWG)

- ■ 4 motors
- ■ 1 DER model
- ■ 143 parameters

JModelica supports dynamic and voltage-dependent models for large buildings.

$$V_{pu} = |V_g| / V_0$$

$$P = P_{base} \left[Z_p V_{pu}^2 + I_p V_{pu} + P_p \right]$$

$$Q = Q_{base} \left[Z_q V_{pu}^2 + I_q V_{pu} + P_q \right]$$

Load	P_0	Z_p	I_p	P_p	Q_0	Z_q	I_q	P_q	pf_0
PC w/ monitor	118.9	0.2	-0.3	1.1	172.79	0	0.6	0.4	0.567
HVAC	496.33	1.17	-1.83	1.66	125.94	15.68	-27.15	12.47	0.969

A. Bokhari, A. Alkan, R. Dogan, M. Diaz-Aguiló, F. d. León, D. Czarkowski, et al., "Experimental Determination of the ZIP Coefficients for Modern Residential, Commercial, and Industrial Loads," IEEE Transactions on Power Delivery, vol. 29, pp. 1372-1381, 2014.

TESP project is replacing detailed ns-3 models with synthetic communication networks from graph theory.

HELICS Components

Scenario Gen.	Configuration	Automation	Visualization

T	Griddyn (Other-T)	D	GridLAB-D (Other-D)	C	ns-3 (Other-C)	M	FESTIV (Other-M)	+	Other Misc.

TDC Optimized Interfaces			HLA	FMI
Federate/Object Management	Event Communication	Scheduler/Time Synchronization		

	Serialization	Distributed Object Store	Distributed Time Synchronization
Communication			
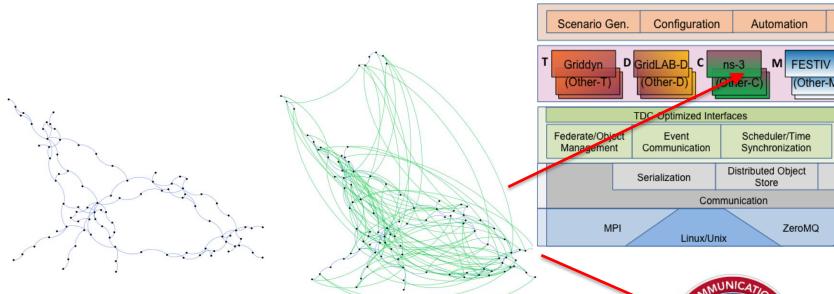
MPI		ZeroMQ	
	Linux/Unix		Windows

Synthesizing communications network
using Python *networkx* and Chung-Lu Chain
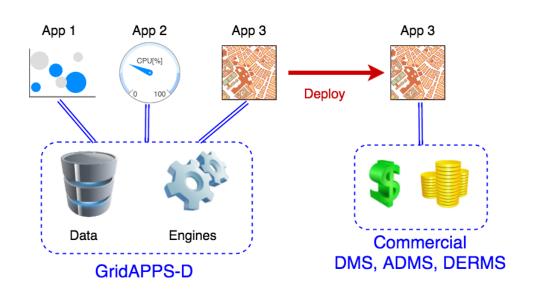
LDRD: Renke Huang and Sinan Aksoy

GridAPPS-D™ is a development platform built around standards, and targeting distributed applications.

Low-TRL Sample Applications

1. Volt-Var optimization
2. Transactive control
3. State estimation (2 teams)
4. Model validation
5. DER optimization (2 teams)
6. Load forecasting
7. Fault recovery
8. Cyber traffic monitor

Raw Measurements →

Sensor Service
- Aggregation
- Errors and dropouts

→ State Estimator
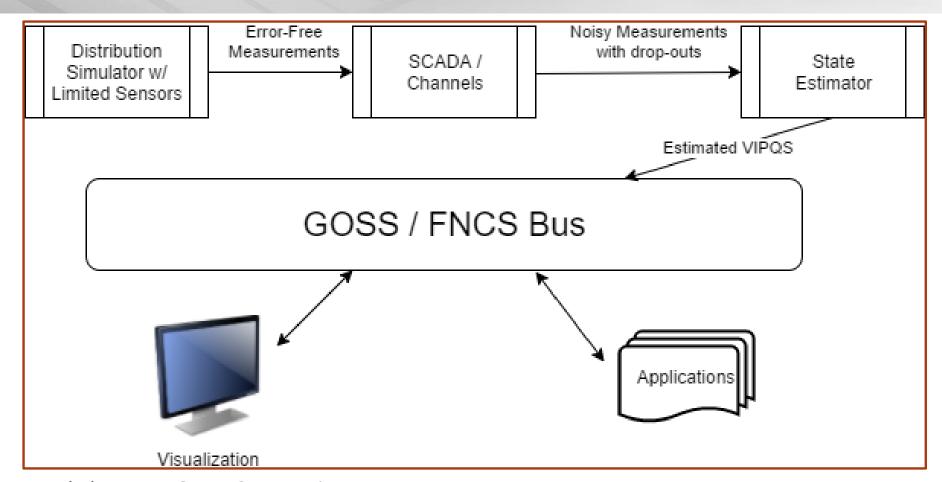
There are three kinds of "measured" values, 1) simulator, 2) sensor outputs, 3) state estimate.

Berkeley-New Open-Source License
Documentation: **http://gridappsd.readthedocs.io**
Code, Examples: **https://github.com/GRIDAPPSD**
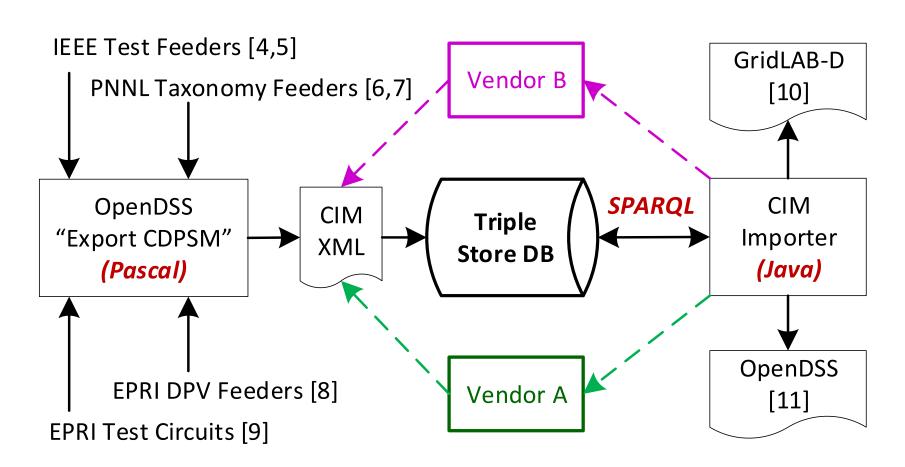
Use of the IEC Standard Common Information Model for OpenFIDO

CIM supports model translation between GridLAB-D, OpenDSS, DMS vendors, CYME, etc.

IEEE Test Feeders [4,5]

PNNL Taxonomy Feeders [6,7]

Vendor B

GridLAB-D [10]

OpenDSS "Export CDPSM" *(Pascal)*

CIM XML

Triple Store DB

SPARQL

CIM Importer *(Java)*

EPRI DPV Feeders [8]

EPRI Test Circuits [9]

Vendor A

OpenDSS [11]
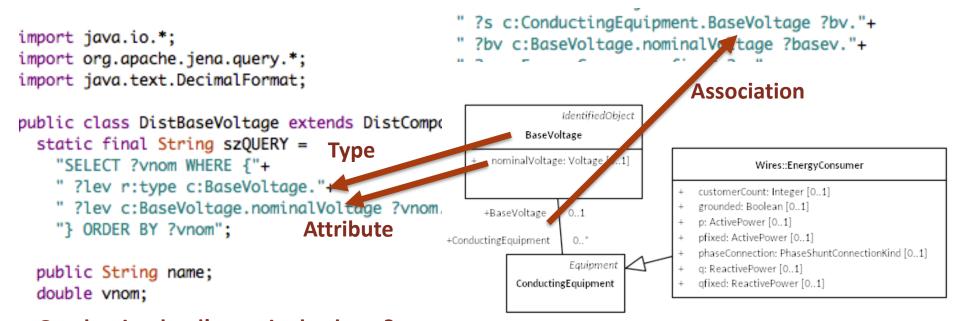
https://github.com/GRIDAPPSD/Powergrid-Models

Common Information Model (CIM) implemented in a triple-store DB for power flow.
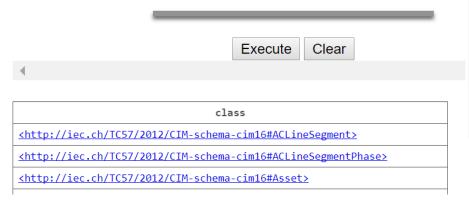
▶ Writes GridLAB-D model and labels in about 5 seconds over HTTP

▶ Imports 329,327 triples in 3.532 seconds

▶ Queries match the CIM; implemented in SPARQL and Java w/ Jena

▶ Outperforms the Relational DBMS (MySQL) version from April 2017

▶ SPARQL (not SQL) lets you write queries directly from UML diagrams

```java
import java.io.*;
import org.apache.jena.query.*;
import java.text.DecimalFormat;

public class DistBaseVoltage extends DistComp
    static final String szQUERY =
        "SELECT ?vnom WHERE {"+
        " ?lev r:type c:BaseVoltage."+
        " ?lev c:BaseVoltage.nominalVoltage ?vnom.
        "} ORDER BY ?vnom";

public String name;
double vnom;
```

```
" ?s c:ConductingEquipment.BaseVoltage ?bv."+
" ?bv c:BaseVoltage.nominalVoltage ?basev."+
```

Association

Type

Attribute

IdentifiedObject
BaseVoltage

+ nominalVoltage: Voltage [..1]

+BaseVoltage   0..1

+ConductingEquipment   0..*

Equipment
ConductingEquipment

Wires::EnergyConsumer

+ customerCount: Integer [0..1]
+ grounded: Boolean [0..1]
+ p: ActivePower [0..1]
+ pfixed: ActivePower [0..1]
+ phaseConnection: PhaseShuntConnectionKind [0..1]
+ q: ReactivePower [0..1]
+ qfixed: ReactivePower [0..1]

Q: what is a load's nominal voltage?

Blazegraph installation and configuration is relatively simple.

▶ Download the jar from https://www.blazegraph.com/download/

▶ On Windows only, patch the configuration:
  - Add to rwstore.properties com.bigdata.rwstore.RWStore.readBlobsAsync=false
  - jar uf blazegraph.jar RWStore.properties

▶ java -server -Xmx4g -Dfile.encoding=UTF-8 -jar blazegraph.jar

▶ Point browser to http://localhost:9999/blazegraph

▶ Load some data from CIM XML file

▶ Run a query in the browser

WELCOME	QUERY	UPDATE

Wiki - SPARQL Query

```
1  SELECT DISTINCT ?class
2  WHERE {
3    ?s a ?class .
4  }
5
```

Execute   Clear
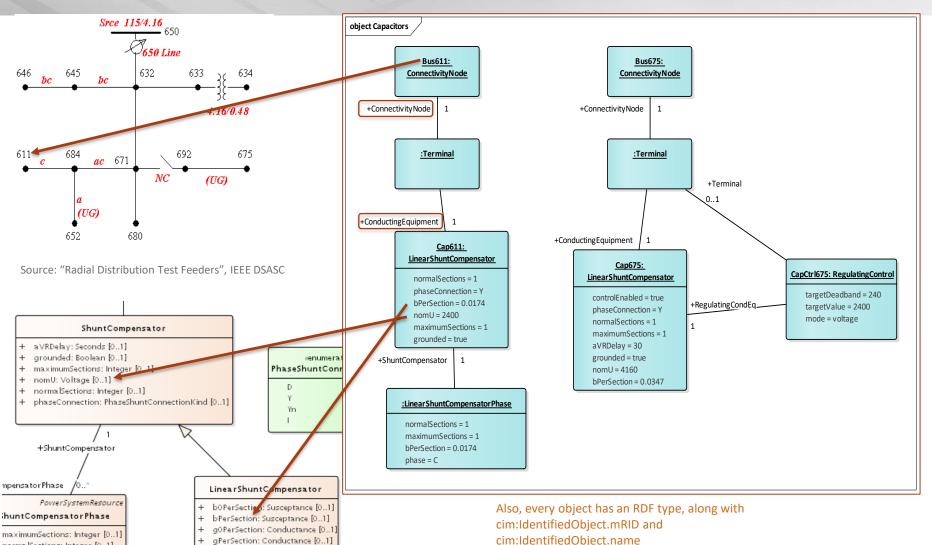
class
<http://iec.ch/TC57/2012/CIM-schema-cim16#ACLineSegment>
<http://iec.ch/TC57/2012/CIM-schema-cim16#ACLineSegmentPhase>
<http://iec.ch/TC57/2012/CIM-schema-cim16#Asset>

Capacitors in CIM; creating SPARQL queries from class and object diagrams

Source: "Radial Distribution Test Feeders", IEEE DSASC

Also, every object has an RDF type, along with cim:IdentifiedObject.mRID and cim:IdentifiedObject.name

Thomas.McDermott@pnnl.gov

September 6, 2018   27
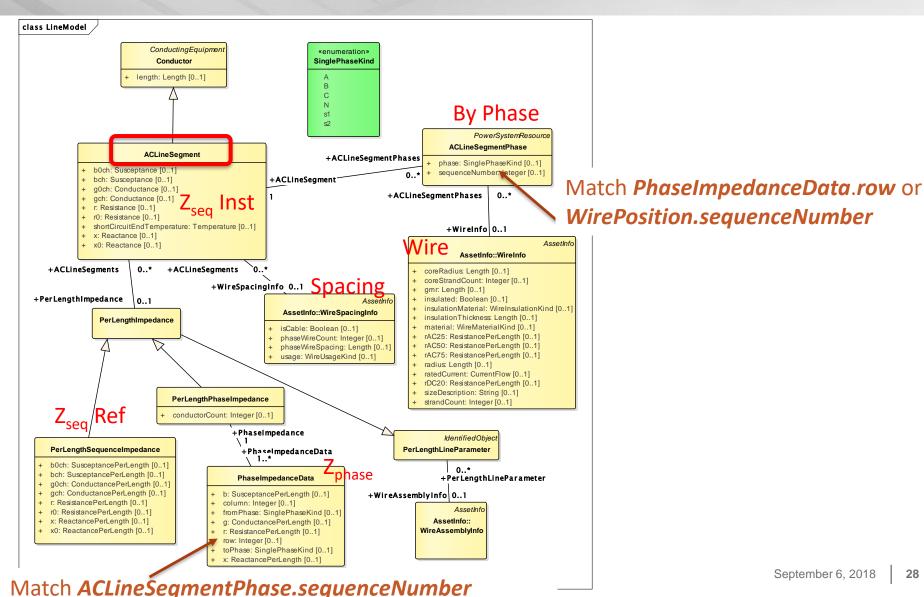
AC Line impedance can be Z_{seq} (by ref or instance), Zphase ref or Spacing/Wire refs.

The WireSpacingInfo / WireInfo catalog maps to phases by sequence number.

class DCIMWireInfo

WireInfo *AssetInfo*
+ coreRadius: Length [0..1]
+ coreStrandCount: Integer [0..1]
+ gmr: Length [0..1]
+ insulated: Boolean [0..1]
+ insulationMaterial: WireInsulationKind [0..1]
+ insulationThickness: Length [0..1]
+ material: WireMaterialKind [0..1]
+ rAC25: ResistancePerLength [0..1]
+ rAC50: ResistancePerLength [0..1]
+ rAC75: ResistancePerLength [0..1]
+ radius: Length [0..1]
+ ratedCurrent: CurrentFlow [0..1]
+ rDC20: ResistancePerLength [0..1]
+ sizeDescription: String [0..1]
+ strandCount: Integer [0..1]

WireSpacingInfo *AssetInfo*
+ isCable: Boolean [0..1]
+ phaseWireCount: Integer [0..1]
+ phaseWireSpacing: Length [0..1]
+ usage: WireUsageKind [0..1]

+WireSpacingInfo 0..1
+WirePositions 1..*

WirePosition *IdentifiedObject*
+ sequenceNumber: Integer [0..1]
+ xCoord: Displacement [0..1]
+ yCoord: Displacement [0..1]

Match ***ACLineSegmentPhase.sequenceNumber***

Not A, B, or C, but 2!

CableInfo
+ constructionKind: CableConstructionKind [0..1]
+ diameterOverCore: Length [0..1]
+ diameterOverInsulation: Length [0..1]
+ diameterOverJacket: Length [0..1]
+ diameterOverScreen: Length [0..1]
+ isStrandFill: Boolean [0..1]
+ nominalTemperature: Temperature [0..1]
+ outerJacketKind: CableOuterJacketKind [0..1]
+ sheathAsNeutral: Boolean [0..1]
+ shieldMaterial: CableShieldMaterialKind [0..1]

OverheadWireInfo

«enumeration» **WireUsageKind**
transmission
distribution
secondary
other

«enumeration» **Wires:: SinglePhaseKind**
A
B
C
N
s1
s2

TapeShieldCableInfo
+ tapeLap: PerCent [0..1]
+ tapeThickness: Length [0..1]

ConcentricNeutralCableInfo
+ diameterOverNeutral: Length [0..1]
+ neutralStrandCount: Integer [0..1]
+ neutralStrandGmr: Length [0..1]
+ neutralStrandRadius: Length [0..1]
+ neutralStrandRDC20: ResistancePerLength [0..1]

«enumeration» **CableShieldMaterialKind**
lead
copper
steel
aluminum
other

«enumeration» **CableConstructionKind**
compacted
compressed
sector
segmental
solid
stranded
other

«enumeration» **WireMaterialKind**
copper
steel
aluminum
aluminumSteel
acsr
aluminumAlloy
aluminumAlloySteel
aaac
other

«enumeration» **WireInsulationKind**
asbestosAndVarnishedCambric
butyl
ethylenePropyleneRubber
highMolecularWeightPolyethylene
treeResistantHighMolecularWeightPolyethylene
lowCapacitanceRubber
oilPaper
ozoneResistantRubber
beltedPilc
unbeltedPilc
rubber
siliconRubber
varnishedCambricCloth
varnishedDacronGlass
crosslinkedPolyethylene
treeRetardantCrosslinkedPolyethylene
highPressureFluidFilled
other

«enumeration» **CableOuterJacketKind**
none
linearLowDensityPolyethylene
pvc
polyethylene
insulating
semiconducting
other

Source: "Radial Distribution Test Feeders", IEEE DSASC

ID-500   ID-505   ID-510

Figure 1 – Overhead Line Spacings

Single-phase, center-tapped secondary transformers serve most house loads in the U.S.

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

Single-phase Service Transformer

A, B, or C

7200

N

Iii

120

(i=0 if balanced)

120

s1

240

N

s2

EnergyConsumer or ACLineSegment

We use tank modeling, asset info and connectivity nodes for flexibility.

No-load tests for catalog entries usually apply to the lowest voltage winding.

```
1   # transformer codes; no-load tests
2   PREFIX r:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3   PREFIX c:   <http://iec.ch/TC57/2012/CIM-schema-cim16#>
4   SELECT ?tname ?nll ?iexc WHERE {
5     ?t r:type c:TransformerTankInfo.
6     ?t c:IdentifiedObject.name ?tname.
7     ?e c:TransformerEndInfo.TransformerTankInfo ?t.
8     ?nlt c:NoLoadTest.EnergisedEnd ?e.
9     ?nlt c:NoLoadTest.loss ?nll.
10    ?nlt c:NoLoadTest.excitingCurrent ?iexc
11  }
12  ORDER BY DESC (?tname)
```

tname	nll	iexc
ct75	0.14999999999999999	0.5
ct50	0.10000000000000001	0.5
ct5	0.01	0.5
ct37	0.074999999999999997	0.5
ct250	0.5	0.5
ct25	0.050000000000000003	0.5
ct15	0.030000000000000002	0.5
ct100	0.20000000000000001	0.5
ct10	0.02	0.5

Short-circuit tests for catalog; match both ends.


```
1   # transformer codes; short-circuit tests
2   PREFIX r:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3   PREFIX c:   <http://iec.ch/TC57/2012/CIM-schema-cim16#>
4   SELECT ?tname ?enum ?gnum ?z ?ll WHERE {
5     ?t r:type c:TransformerTankInfo.
6     ?t c:IdentifiedObject.name ?tname.
7     ?e c:TransformerEndInfo.TransformerTankInfo ?t.
8     ?e c:TransformerEndInfo.endNumber ?enum.
9     ?grnd c:TransformerEndInfo.endNumber ?gnum.
10    ?sct c:ShortCircuitTest.EnergisedEnd ?e.
11    ?sct c:ShortCircuitTest.GroundedEnds ?grnd.
12    ?sct c:ShortCircuitTest.leakageImpedance ?z.
13    ?sct c:ShortCircuitTest.loss ?ll.
14  }
15  ORDER BY DESC (?tname) ?enum ?gnum
```

tname	enum	gnum	z	ll
ct75	1	2	14.100480000000003	1.3500000000000001
ct75	1	3	14.100480000000003	0
ct75	2	3	0.0026111999999999997	0
ct50	1	2	21.15072	0.90000000000000013
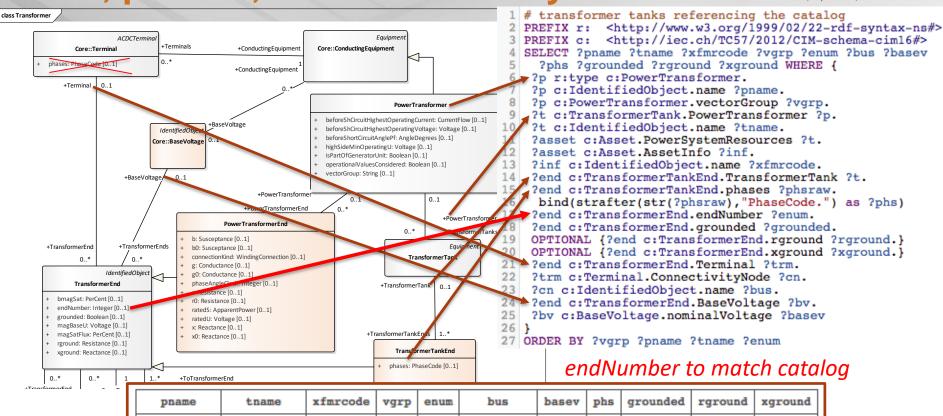
Connecting the transformer to catalog data, phases, and connectivity nodes.

```
1   # transformer tanks referencing the catalog
2   PREFIX r:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3   PREFIX c:   <http://iec.ch/TC57/2012/CIM-schema-cim16#>
4   SELECT ?pname ?tname ?xfmrcode ?vgrp ?enum ?bus ?basev
5     ?phs ?grounded ?rground ?xground WHERE {
6   ?p r:type c:PowerTransformer.
7   ?p c:IdentifiedObject.name ?pname.
8   ?p c:PowerTransformer.vectorGroup ?vgrp.
9   ?t c:TransformerTank.PowerTransformer ?p.
10  ?t c:IdentifiedObject.name ?tname.
11  ?asset c:Asset.PowerSystemResources ?t.
12  ?asset c:Asset.AssetInfo ?inf.
13  ?inf c:IdentifiedObject.name ?xfmrcode.
14  ?end c:TransformerTankEnd.TransformerTank ?t.
15  ?end c:TransformerTankEnd.phases ?phsraw.
16    bind(strafter(str(?phsraw),"PhaseCode.") as ?phs)
17  ?end c:TransformerEnd.endNumber ?enum.
18  ?end c:TransformerEnd.grounded ?grounded.
19  OPTIONAL {?end c:TransformerEnd.rground ?rground.}
20  OPTIONAL {?end c:TransformerEnd.xground ?xground.}
21  ?end c:TransformerEnd.Terminal ?trm.
22  ?trm c:Terminal.ConnectivityNode ?cn.
23  ?cn c:IdentifiedObject.name ?bus.
24  ?end c:TransformerEnd.BaseVoltage ?bv.
25  ?bv c:BaseVoltage.nominalVoltage ?basev
26  }
27  ORDER BY ?vgrp ?pname ?tname ?enum
```

endNumber to match catalog

pname	tname	xfmrcode	vgrp	enum	bus	basev	phs	grounded	rground	xground
t0107636a	t0107636a	ct25	Iii	1	13030204	12470	A	false		
t0107636a	t0107636a	ct25	Iii	2	x3030204a	208	s1	false		
t0107636a	t0107636a	ct25	Iii	3	x3030204a	208	s2	false		
t0107693b	t0107693b	ct25	Iii	1	13160868	12470	B	false		
t0107693b	t0107693b	ct25	Iii	2	x3160868b	208	s1	false		
t0107693b	t0107693b	ct25	Iii	3	x3160868b	208	s2	false		

PV and Storage modeling in CIM should cover the superset of GridLAB-D and OpenDSS features.

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** Since 1965

GridLAB-D Bus

OpenDSS Bus

CIM v17 has been extended to support basic power flow solutions in GridLAB-D & OpenDSS.

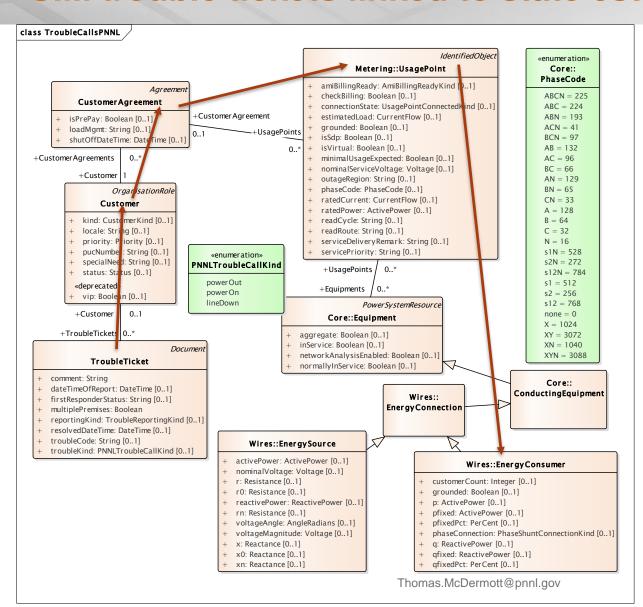# The Outage Management System (OMS) with CIM trouble tickets linked to state estimator.

class TroubleCallsPNNL

CustomerAgreement *(Agreement)*
- + isPrePay: Boolean [0..1]
- + loadMgmt: String [0..1]
- + shutOffDateTime: DateTime [0..1]

+CustomerAgreement   0..1
+CustomerAgreements   0..*
+Customer   1

Customer *(OrganisationRole)*
- + kind: CustomerKind [0..1]
- + locale: String [0..1]
- + priority: Priority [0..1]
- + pucNumber: String [0..1]
- + specialNeed: String [0..1]
- + status: Status [0..1]
- «deprecated»
- + vip: Boolean [0..1]

+Customer   0..1
+TroubleTickets   0..*

TroubleTicket *(Document)*
- + comment: String
- + dateTimeOfReport: DateTime [0..1]
- + firstResponderStatus: String [0..1]
- + multiplePremises: Boolean
- + reportingKind: TroubleReportingKind [0..1]
- + resolvedDateTime: DateTime [0..1]
- + troubleCode: String [0..1]
- + troubleKind: PNNLTroubleCallKind [0..1]

«enumeration» PNNLTroubleCallKind
- powerOut
- powerOn
- lineDown

Metering::UsagePoint *(IdentifiedObject)*
- + amiBillingReady: AmiBillingReadyKind [0..1]
- + checkBilling: Boolean [0..1]
- + connectionState: UsagePointConnectedKind [0..1]
- + estimatedLoad: CurrentFlow [0..1]
- + grounded: Boolean [0..1]
- + isSdp: Boolean [0..1]
- + isVirtual: Boolean [0..1]
- + minimalUsageExpected: Boolean [0..1]
- + nominalServiceVoltage: Voltage [0..1]
- + outageRegion: String [0..1]
- + phaseCode: PhaseCode [0..1]
- + ratedCurrent: CurrentFlow [0..1]
- + ratedPower: ActivePower [0..1]
- + readCycle: String [0..1]
- + readRoute: String [0..1]
- + serviceDeliveryRemark: String [0..1]
- + servicePriority: String [0..1]

+UsagePoints   0..*
+UsagePoints   0..*
+Equipments   0..*

Core::Equipment *(PowerSystemResource)*
- + aggregate: Boolean [0..1]
- + inService: Boolean [0..1]
- + networkAnalysisEnabled: Boolean [0..1]
- + normallyInService: Boolean [0..1]

Core:: ConductingEquipment

Wires:: EnergyConnection

Wires::EnergySource
- + activePower: ActivePower [0..1]
- + nominalVoltage: Voltage [0..1]
- + r: Resistance [0..1]
- + r0: Resistance [0..1]
- + reactivePower: ReactivePower [0..1]
- + rn: Resistance [0..1]
- + voltageAngle: AngleRadians [0..1]
- + voltageMagnitude: Voltage [0..1]
- + x: Reactance [0..1]
- + x0: Reactance [0..1]
- + xn: Reactance [0..1]

Wires::EnergyConsumer
- + customerCount: Integer [0..1]
- + grounded: Boolean [0..1]
- + p: ActivePower [0..1]
- + pfixed: ActivePower [0..1]
- + pfixedPct: PerCent [0..1]
- + phaseConnection: PhaseShuntConnectionKind [0..1]
- + q: ReactivePower [0..1]
- + qfixed: ReactivePower [0..1]
- + qfixedPct: PerCent [0..1]

«enumeration» Core:: PhaseCode

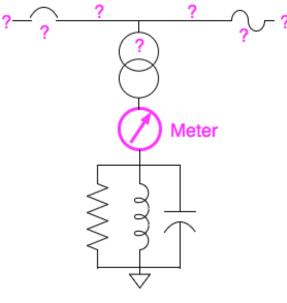| Code	Value
ABCN	225
ABC	224
ABN	193
ACN	41
BCN	97
AB	132
AC	96
BC	66
AN	129
BN	65
CN	33
A	128
B	64
C	32
N	16
s1N	528
s2N	272
s12N	784
s1	512
s2	256
s12	768
none	0
X	1024
XY	3072
XN	1040
XYN	3088

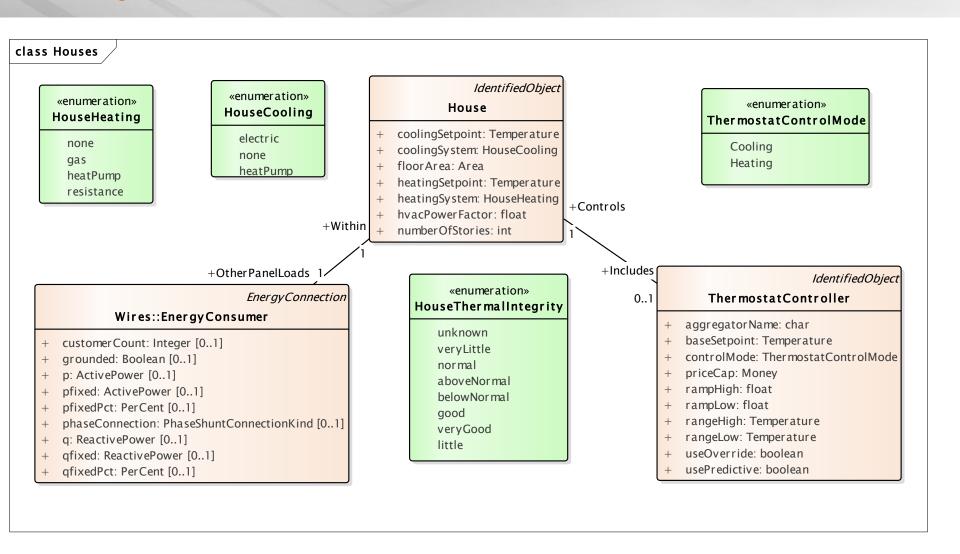**Trouble Call**
- Customer
- Address
- Meter #
- Start Time
- End Time
- Type (power out, line down)

Meter

GridAPPS-D needs a minimal CIM house for repeatable realistic load simulations.

class Houses

«enumeration»
HouseHeating

none
gas
heatPump
resistance

«enumeration»
HouseCooling

electric
none
heatPump

IdentifiedObject
House

+   coolingSetpoint: Temperature
+   coolingSystem: HouseCooling
+   floorArea: Area
+   heatingSetpoint: Temperature
+   heatingSystem: HouseHeating
+   hvacPowerFactor: float
+   numberOfStories: int

«enumeration»
ThermostatControlMode

Cooling
Heating

+Within

+Controls

+OtherPanelLoads

+Includes

EnergyConnection
Wires::EnergyConsumer

+   customerCount: Integer [0..1]
+   grounded: Boolean [0..1]
+   p: ActivePower [0..1]
+   pfixed: ActivePower [0..1]
+   pfixedPct: PerCent [0..1]
+   phaseConnection: PhaseShuntConnectionKind [0..1]
+   q: ReactivePower [0..1]
+   qfixed: ReactivePower [0..1]
+   qfixedPct: PerCent [0..1]

«enumeration»
HouseThermalIntegrity

unknown
veryLittle
normal
aboveNormal
belowNormal
good
veryGood
little

IdentifiedObject
ThermostatController

+   aggregatorName: char
+   baseSetpoint: Temperature
+   controlMode: ThermostatControlMode
+   priceCap: Money
+   rampHigh: float
+   rampLow: float
+   rangeHigh: Temperature
+   rangeLow: Temperature
+   useOverride: boolean
+   usePredictive: boolean

California DER/DRP Modeling Tools Development

6 September 2018

Powernet, OpenFIDO, HiPAS, and GLOW

Overview

Four CEC-funded projects that use GridLAB-D
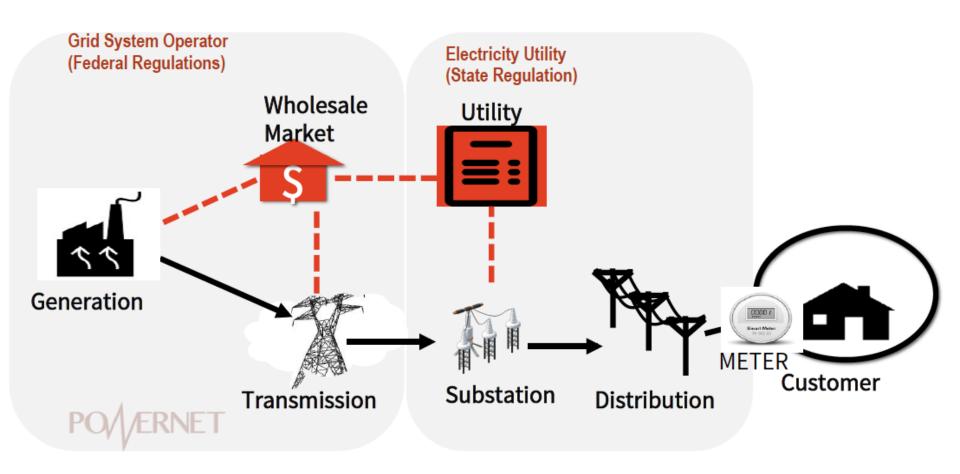
- PowerNET with Markets (EPC 15-047, SLAC)

- OpenFIDO (EPC 17-047, SLAC, PNNL, Gridworks, National Grid)

- HiPAS (EPC 17-046, SLAC, PNNL, Gridworks, National Grid)

- GLOW (EPC 17-043, Hitachi, SLAC, PNNL, Gridworks, National Grid)
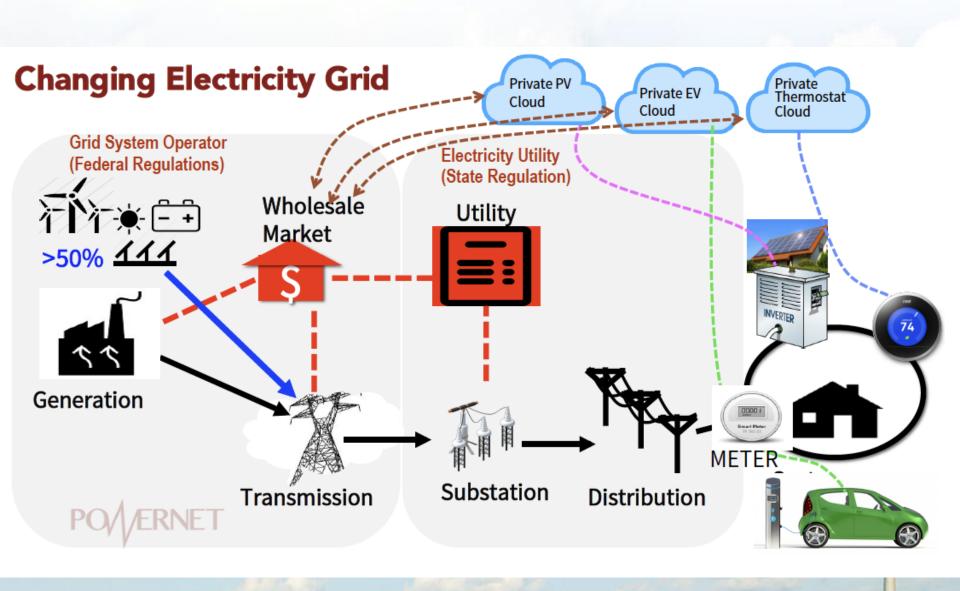
PowerNet with Markets: DER Integration Modeling

Demonstrate/evaluate performance of scaling distributed resource control

- Key questions being investigated
  - How easy is it to integrate distributed/centralized dispatch strategies?
  - How attractive is this to customers?
  - How ready is industry to adopt products?

- Unique combinations of technologies being tested
  - Power electronic control at end-use loads
  - Machine learning of consumer/device behavior
  - Realistic scaling of cloud-based coordination or DER

Changing Electricity Grid

Changing Electricity Grid

Private PV Cloud

Private EV Cloud

Private Thermostat Cloud

Grid System Operator (Federal Regulations)

>50%

Generation

Wholesale Market

$

Transmission

Electricity Utility (State Regulation)

Utility

Substation

Distribution

INVERTER

74

METER

POWERNET
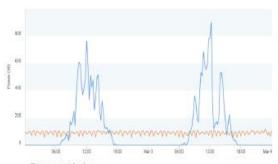
Challenges and opportunities

Challenges

- RE generation is variable

Powernet Lab:
Solar generation – blue; Total consumption - orange
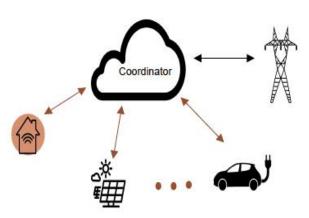
- New devices with new dynamics and capabilities added to the network

Current waveform of power electronics' interfaced load

Opportunity
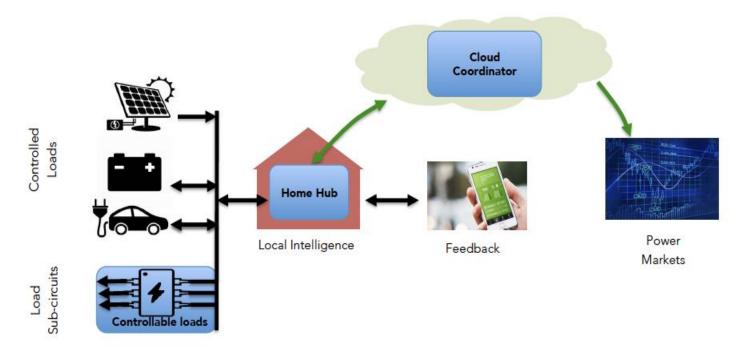
Coordination platform:
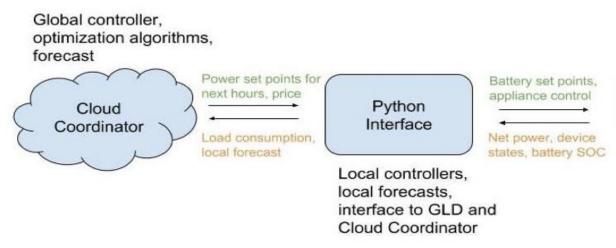
Powernet – What is it?

- Coordination of capacity resources to shave peaks and provide grid services
- Enable smart homes and buildings
- Autonomous operations constrained by user preferences and price rates

POWERNET

Powernet – Simulation Platform

Global controller, optimization algorithms, forecast

Network simulation (up to 10k homes), detailed home models at appliance and DER level

Cloud Coordinator

Power set points for next hours, price

Load consumption, local forecast

Python Interface

Battery set points, appliance control

Net power, device states, battery SOC

GridLAB-D

Local controllers, local forecasts, interface to GLD and Cloud Coordinator
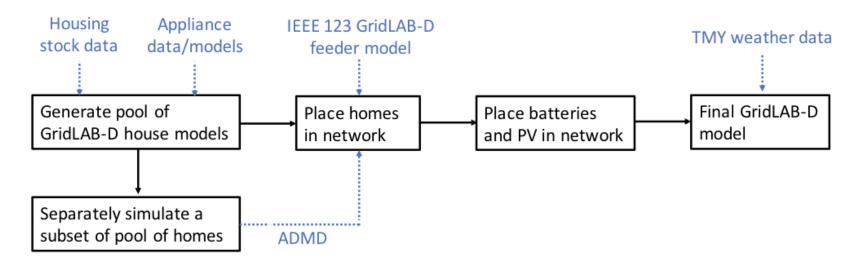
Integration of GridLAB-D with the Cloud Coordintor and the Home Hub in the simulator

• The HOME HUB senses the power consumption per circuit breaker in the house, device status and state of the charge of the battery.

POWERNET

Powernet – Simulation Platform - Hardware in Loop

Housing stock data → Generate pool of GridLAB-D house models

Appliance data/models → Generate pool of GridLAB-D house models

IEEE 123 GridLAB-D feeder model → Place homes in network

TMY weather data → Final GridLAB-D model

Generate pool of GridLAB-D house models → Place homes in network → Place batteries and PV in network → Final GridLAB-D model

Generate pool of GridLAB-D house models → Separately simulate a subset of pool of homes

Separately simulate a subset of pool of homes → (ADMD) → Place homes in network

Pool of house models was created combining different features: 1-2 stories, different appliances and cooling-heater systems, house cost, floor area, air change rate, window to wall ratio, etc.

POWERNET

DRP Modeling Program Overview

1. **Program Overview**

   - Motivation, benefits, & objectives
   - TAC coordination/schedule/members

2. **Technical Approach**

   - Perspective/architecture/GridLAB-D
   - GLOW
   - HiPAS
   - OpenFIDO

3. **Budget and Timeline**

   - Timeline/coordination
   - Budget overview

4. **Consortium Planning**

   - Motivation
   - Challenges
   - Success stories

Project Teams & Key Staff

Hitachi America Labs

- <u>Dr. Bo Yang</u> (GLOW PM)
- Sadanori Horiguchi
- Dr. Yanzhu Ye
- Sumito Tobe

Stanford/SLAC

- <u>Dr. David Chassin</u> (HiPAS/OpenFIDO PM)
- Dr. Chin-Woo Tan (HiPAS/OpenFIDO DPM)
- Alyona Ivanova (modeling and validation)
- Berk Serbetcioglu (performance tools)
- Supriya Premkumar (user interface APIs)

Gridworks

- <u>Matthew Tisdale</u>
- Alex Smith

Battelle/PNNL

- Dr. Tom McDermott (OpenFIDO)
- Jason Fuller (HiPAS/GLOW)

National Grid

- Dr. Pedram Jahangiri

CEC-Funded Projects

Programmatic effort to support decision of Commissioner Picker of 2/25/18

GridLAB-D Open-source Workspace (GLOW - EPC 17-043)

- General user interface for GridLAB-D
- Focus on use-cases in Grid Modernization investments

High-Performance Agent-based Simulation (HiPAS - EPC 17-046)

- High-performance simulation in GridLAB-D
- Focus on supporting DRP Tracks 1 (Tools) proceeding use-cases

Open Framework for Integrated Data Operations (OpenFIDO - EPC 17-047)

- Energy data interoperability for California (CPUC, utilities, consultants, etc.)
- Focus on support of DRP Track 2 (Data Access Portal) use case

Motivation

Vision for all three projects

- Enable DRP user-cases (see Com. Picker Decision, R.14-08-013) analysis using GridLAB-D

- Support and leverage California leadership in renewable integration and adoption

- Focus GridLAB-D R&D community on California's electricity system needs

- Establish basis for long-term support of GridLAB-D in California

Address critical modeling tool needs in California

- A user-interface for GridLAB-D (GLOW)

- High-performance modeling and simulation in GridLAB-D (HiPAS)

- Data interoperability for system planning and operation studies (OpenFIDO)

Project Benefits/Impacts

Anticipated benefits

- Shorten time/cost, while increasing transparency, of DRP analysis activities

- Get ahead of future grid modeling issues in California

- Create lasting impact through more usable versions of GridLAB-D

- Enable high levels of DER, DR and EV technology in distribution systems

Highlights of Kick-off Benefits Questionnaire

- Enable stakeholder insight into dynamic optimization of grid operations and resources

- Feeds 14+ CPUC rulemakings; impact on CEC policy-making, utility planning, DER integration

- Bridge to other grid modeling tools (OpenFIDO) and increase computational power (HiPAS)

TAC Coordination

One Coordinated TAC for All Three Projects

Participant	What they bring
CPUC	Expert in policy context which will define current and future needs
DOE	Expert in GridLAB-D applications and ongoing-R&D
Utilities	Expert in GridLAB-D's role in grid analytics, past, present and future
DER Vendors	Expert in current and future use-cases for GridLAB-D; future users
Environmental NGOs	Independent outside perspective, anticipating future needs

TAC Members

Government

- Justin Regnier (CPUC)
- Eric Lightner (US DOE)

Industry/Vendors

- Audrey Lee (Sunrun)
- Jim Baak (STEM)

Public Interest

- Merrian Borgeson (NRDC)
- Davianna Olert (EDF)

Industry/Users

- Kristen Brown (ComEd)
- Tom Russell (PG&E)
- Aram Shumavon (Kevala)
- Pedram Jahangiri (National Grid)
- Raul Perez-Guerrero (SCE)
- Rachel Huang (SMUD)

TAC Schedule

Date	Milestone
September 6 + 7 , 2018	Workshop and TAC Meeting
September - October	One-on-one Interviews with Project Leads and TAC Members
Annual September Meetings	TAC Convened Annually for Project Update and Input
Ad hoc	Additional TAC engagement as project needs arise

Technical Perspective
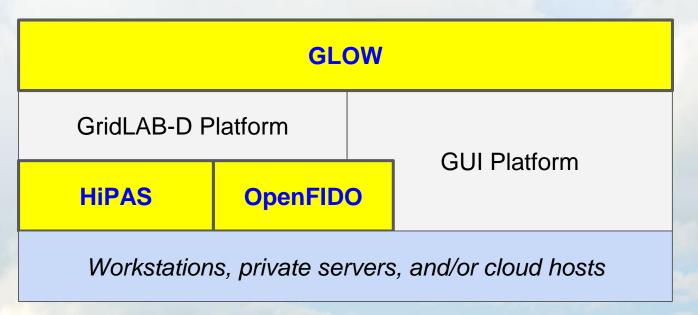
GridLAB-D basis for modeling and simulation work

- GLOW focus on use-cases for user interface for modeling and simulation

- HiPAS focus on latest high-performance and scalable solver technology

Platform for data integration with other tools (OpenFIDO)

- Compatibility with tools used widely in California

- Emphasis on standards-based formats (e.g., CIM)

- Support for modern high-performance storage technology (cloud, triple-store)

- Support for entire data pipeline including models, weather, AMI, SCADA, etc.

System Architecture

GLOW	
GridLAB-D Platform	GUI Platform
HiPAS · OpenFIDO	
Workstations, private servers, and/or cloud hosts	

Legend:

Project deliverable

Open source library

User determined

GLOW (Hitachi)

1. **Software specification**
- Human-machine interaction, information architecture, visual design; Representative use cases (workflow), I/O requirements, **UI support for OpenFIDO/HiPAS**

1. **Software development**
- Fast prototype, agile development, early integration with GridLAB-D, automatic testing environment

1. **Software testing**
   a. Alpha - Functionality, interface with GridLAB-D/OpenFIDO/HiPAS, comply to standard testing process
   b. Beta - Quality, robustness and performance
   c. Usability testing - Ease of use, UI flexibility, overall system performance

2. **Software release**
- Coordinated release with OpenFIDO/HiPAS/GridLAB-D

1. **Maintenance**
- In project + 5 yr post project

HiPAS (SLAC)

1.   Multithreaded iterators

- Deploy highly granular parallelization within the structure of GridLAB-D models.

2.   Job control

- Enable large-scale batch runs of parametric models for distribution planning studies.

3.   Multithreaded solvers

- Enable fast simulations by running independent agent solutions in parallel.

4.   Stochastic properties

- Allow representation of correlated properties to reduce the number of batch runs needed to complete planning studies.

5.   Large data access

- Enable high-performance simulations when using large amount of data (e.g., SCADA, AMI).

6.   Fast powerflow solvers

- Implement a machine learning-based solvers to reduce overall simulation runtime.

OpenFIDO (SLAC)
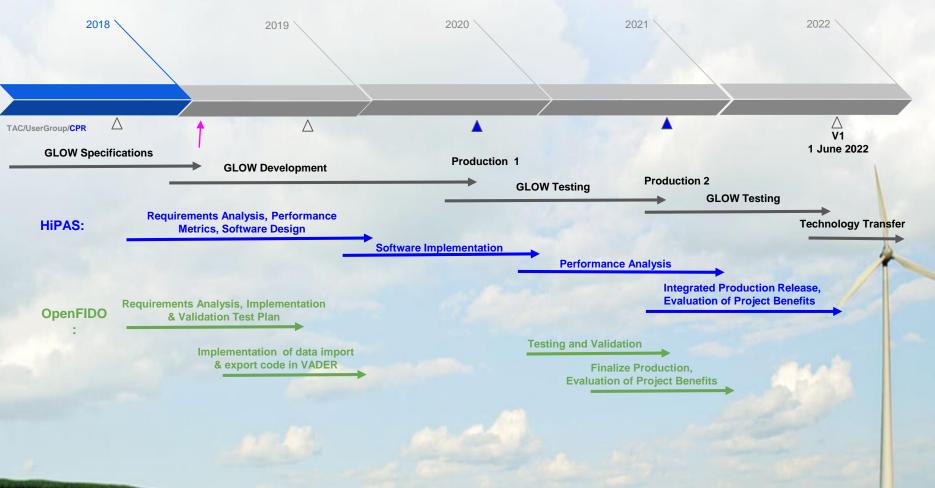
1. **Technical Approach**

   a. Data import, interchange, storage and export of system data between tool users using VADER

   b. Focus on data exchange for IOUs, CPUC, vendors and DRP use-cases

   c. Implementation activities supporting GridLAB-D (coordination with HiPAS and GLOW)

2. **PNNL Activities**

   a. Webinars on CIM modeling capabilities from DOE

   b. Engage vendors in building data exchange platform

   c. Testing/validation based on feeder models from IOUs

Project timeline and coordination

2018 2019 2020 2021 2022

TAC/UserGroup/CPR

V1
1 June 2022

GLOW Specifications

GLOW Development

Production 1

GLOW Testing

Production 2

GLOW Testing

Technology Transfer

HiPAS:

Requirements Analysis, Performance Metrics, Software Design

Software Implementation

Performance Analysis

Integrated Production Release, Evaluation of Project Benefits

OpenFIDO:

Requirements Analysis, Implementation & Validation Test Plan

Implementation of data import & export code in VADER

Testing and Validation

Finalize Production, Evaluation of Project Benefits

Budget Overview

	GLOW	HiPAS	OpenFIDO	Total
Hitachi	1,861,881 [1,175,060]	0	0	**1,861,881 [1,175,060]**
SLAC	680,000	2,740,782	910,225	**4,331,007**
Gridworks	399,818	269,999	39,964	**709,781**
PNNL	58,000	58,000	49,811	**165,811**
National Grid	[80,000]	[300,000]	[30,000]	**[410,000]**
Total	**2,999,699 [1,255,060]**	**3,068,781 [300,000]**	**1,000,000 [30,000]**	**7,068,480 [1,585,060]**

Notes:
1. Quantities in [] brackets indicate cost share and/or matching funds

GridLAB-D Consortium

Motivations

- Support of collaboration-based development
- Guaranteed code contribution after projects
- Timely support for future users and developers
- Outreach to further expand user groups

Challenges

- Value propositions to interested entities
- Initial funding and program guidance
- Governance and operating principles

Success stories

Linux foundation

Mission: accelerate open source technology development and adoption

Overview: Founded in 2000 / 1000+ corporate member / 85 projects / 16B USD shared development efforts

Services: Hosting OSS projects / trainings / events / Standards

Hyperledger Fabric

Mission: Open source collaborative efforts to advance blockchain technologies

Overview: Launched in 2016 / ~200 corporate and associate members

Services: Create enterprise grade software framework and code basis / community-driven infrastructure support / Build technical use cases / Outreach and education

Questions and Discussion

Lunch Break

1:30 Session 3: Pedram Jahangiri (National Grid)

GridLAB-D in California's Distributed Energy Policy Landscape

September 6, 2018
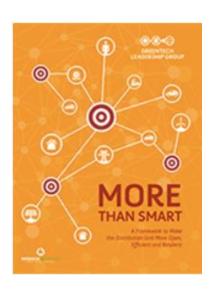
PRESENTATION OVERVIEW

1. Introduction

2. Distribution Resource Planning in California

3. Example: PG&E

4. GLOW in Context

5. Observations

INTRODUCTION

The Gridworks mission is to convene, educate and empower stakeholders to decarbonize electricity grids.

California's Distribution Resource Planning

- *Develop new tools, processes, and investment frameworks that enable IOUs to better integrate DERs into grid operations and the annual distribution planning process*
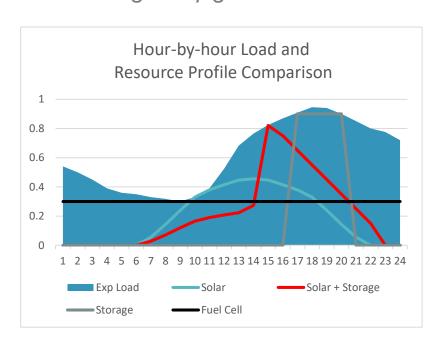
  - *Tools: ICA, LNBA*
  - *Processes: distribution annual planning, DER adoption & load growth forecasting*
  - *Investment frameworks: grid mod investment, distribution deferral*

Integration Capacity Analysis:
Distribution system modeling and power flow analysis

Calculates available circuit hosting capacity to accommodate additional DERs w/o grid upgrades

Hour-by-hour Load and Resource Profile Comparison

Legend: Exp Load, Solar, Solar + Storage, Storage, Fuel Cell
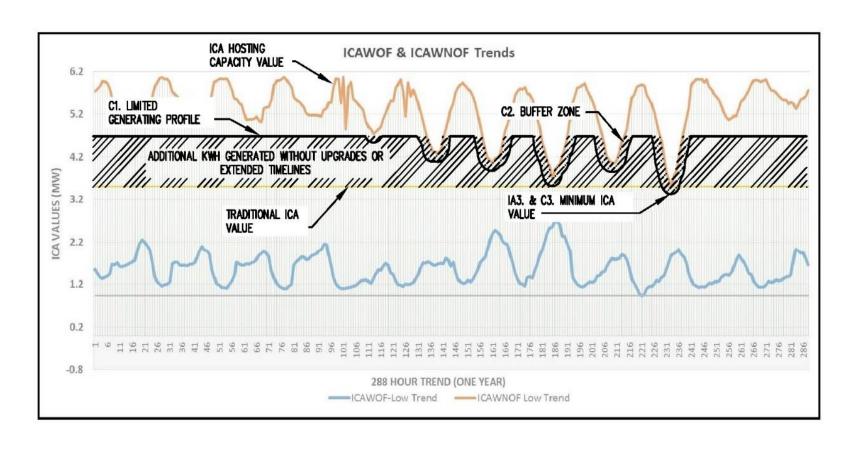
Two primary use cases:

1. *Inform DER developers of grid locations where DERs can interconnect without system upgrades (see next slide)*

2. *Inform annual distribution planning, e.g. where to proactively upgrade the grid to accommodate expected DER growth.*
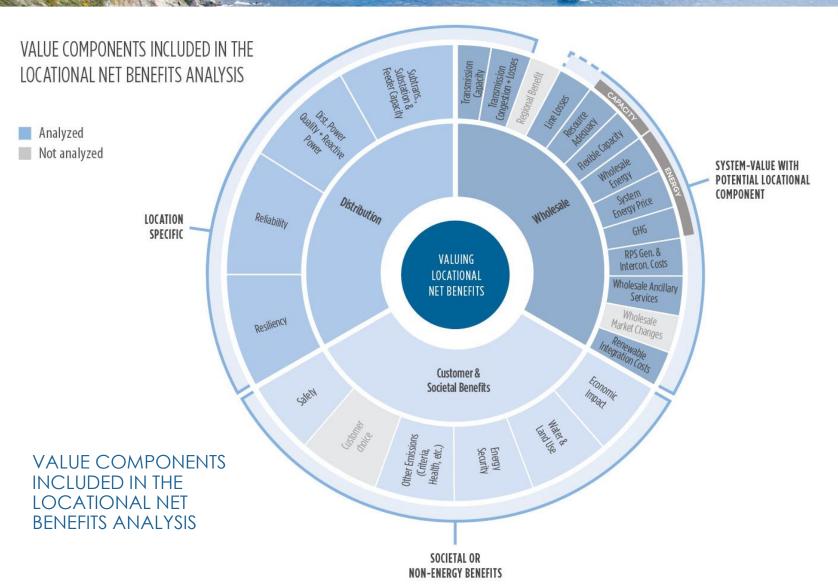
ICA Integration into Interconnection Policies

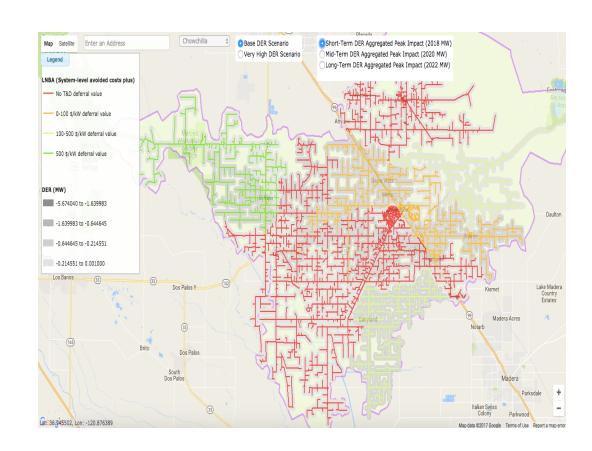VALUE COMPONENTS INCLUDED IN THE LOCATIONAL NET BENEFITS ANALYSIS

Analyzed
Not analyzed

VALUE COMPONENTS INCLUDED IN THE LOCATIONAL NET BENEFITS ANALYSIS

LOCATION SPECIFIC

SYSTEM-VALUE WITH POTENTIAL LOCATIONAL COMPONENT

SOCIETAL OR NON-ENERGY BENEFITS

VALUING LOCATIONAL NET BENEFITS

Distribution

Wholesale

Customer & Societal Benefits

Subtrans., Substation & Feeder Capacity

Dist. Power Quality + Reactive Power

Reliability

Resiliency

Safety

Customer choice

Other Emissions (Criteria, Health, etc.)

Energy Security

Water & Land Use

Economic Impact

Renewable Integration Costs

Wholesale Market Changes

Wholesale Ancillary Services

RPS Gen. & Intercon. Costs

GHG

System Energy Price

Wholesale Energy

Flexible Capacity

Resource Adequacy

Line Losses

Regional Benefit

Transmission Congestion + Losses

Transmission Capacity

CAPACITY
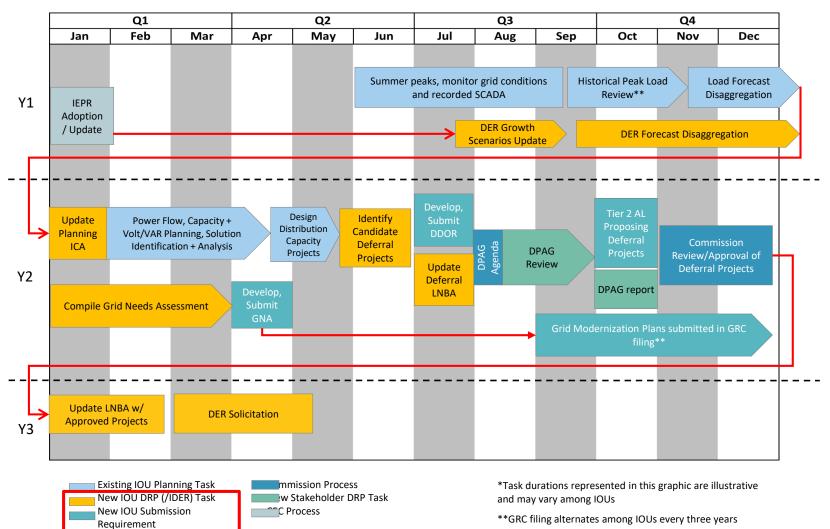
ENERGY

Locational Net Benefits Analysis Use Cases

Three primary use cases:

1. *cost-effectiveness studies to indicate high-value locations for distributed energy resource (DER) deployment*

2. *inform resource procurement decisions,*

3. *develop rates or tariffs for sourcing DERs*

Existing Distribution Planning Process and New Distribution Resource Planning Cycle*

*Task durations represented in this graphic are illustrative and may vary among IOUs

**GRC filing alternates among IOUs every three years

Example: PG&E

Summary of Distribution Planning Tools

Investment
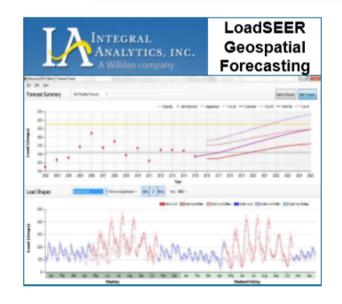
- Enhance distribution feeder load profiles by integrating AMI information

- Integrate power flow analysis & demand forecast tools (e.g. CYME & LoadSEER)

- Deploy data analytics engine to detect phase imbalance for planning and operations tools

- Develop integration capacity analysis (ICA) Tool to calculate hosting capacity

Benefits

- Enables better planning with more granular data and enhances capabilities to inform operational tools and better plan for two-way power flow

- Creates a data pathway for the granular profile information mentioned earlier to be able to feed multiple planning or operational tools

- Phase identification increases accuracy and efficiency in planning and operation the grid

- Helps integration of DER by enabling more cost effective and optimal siting through more precision and accuracy of impact analysis. Proactively identifies two-way power flow conditions.
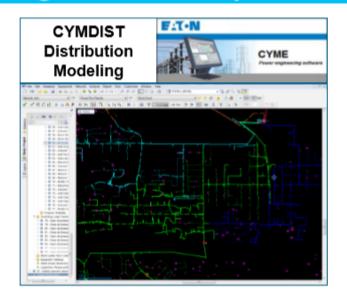
Integrate Distribution Load Flow and Forecasting Tools to enhance granular modeling of DER adoption

LoadSEER Geospatial Forecasting (INTEGRAL ANALYTICS, INC. A Willdan company)

CYMDIST Distribution Modeling (EATON / CYME Power engineering software)

Distribution topology/configuration ←

Hourly loading and forecast data →

Benefits

- **Increased knowledge of topology** to inform transfers and forecasts
- More **accurate load shapes** due to knowledge of topology and customer locations

Benefits

- Provides detailed customer load profile data for **more accurate simulation**
- Automatic push of forecast information for **easier forecast scenario analysis** on distribution circuits

Creates a data pathway for the granular profile information mentioned earlier to be able to feed multiple planning or operational tools

Current technical challenges- ICA example

- *Modeling limitations: Existing tools capture steady-state and fast-transient, but lack mesoscale.*

- *Long run times per circuit*

- *Other technical challenges (e.g., this summer PG&E's ICA model keeps "crashing")*

- *3rd party developer support solutions?*

Where does GridLAB-D fit in?

Expected uses of HiPAS, OpenFIDO, and GLOW – California regulatory context

- *Support targeted deployment of DER for easier interconnection and high-value locations*

    - *Proposed users: utilities, DER developers*

- *Support utilities' annual planning process to identify areas for upgrades, and plan for DERs*

    - *Proposed users: utilities, regulators, ratepayer advocates, DER developers and advocates*

- *Inform policy decisions (e.g., understanding the impact of a new policy or program on the distribution system)*

    - *Proposed users: utilities, regulators, ratepayer advocates, DER developers?*

Observations

- *Proactively integrating DERs into the planning process: it takes time, trial and error to get the tools, processes, and investment frameworks correct*

- *More users of what were formerly utility-only planning tools*

- *Tools must evolve as the system and the applications become more complex to solve the future needs of the grid*

THANK YOU!

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Next Steps

Open Discussion

Recap

Upcoming meetings