Demonstration: Plugin EVs for Frequency Regulation

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NIST Workshop on
Power Conditioning System Architecture
for Plugin Vehicle Fleets as Grid Storage

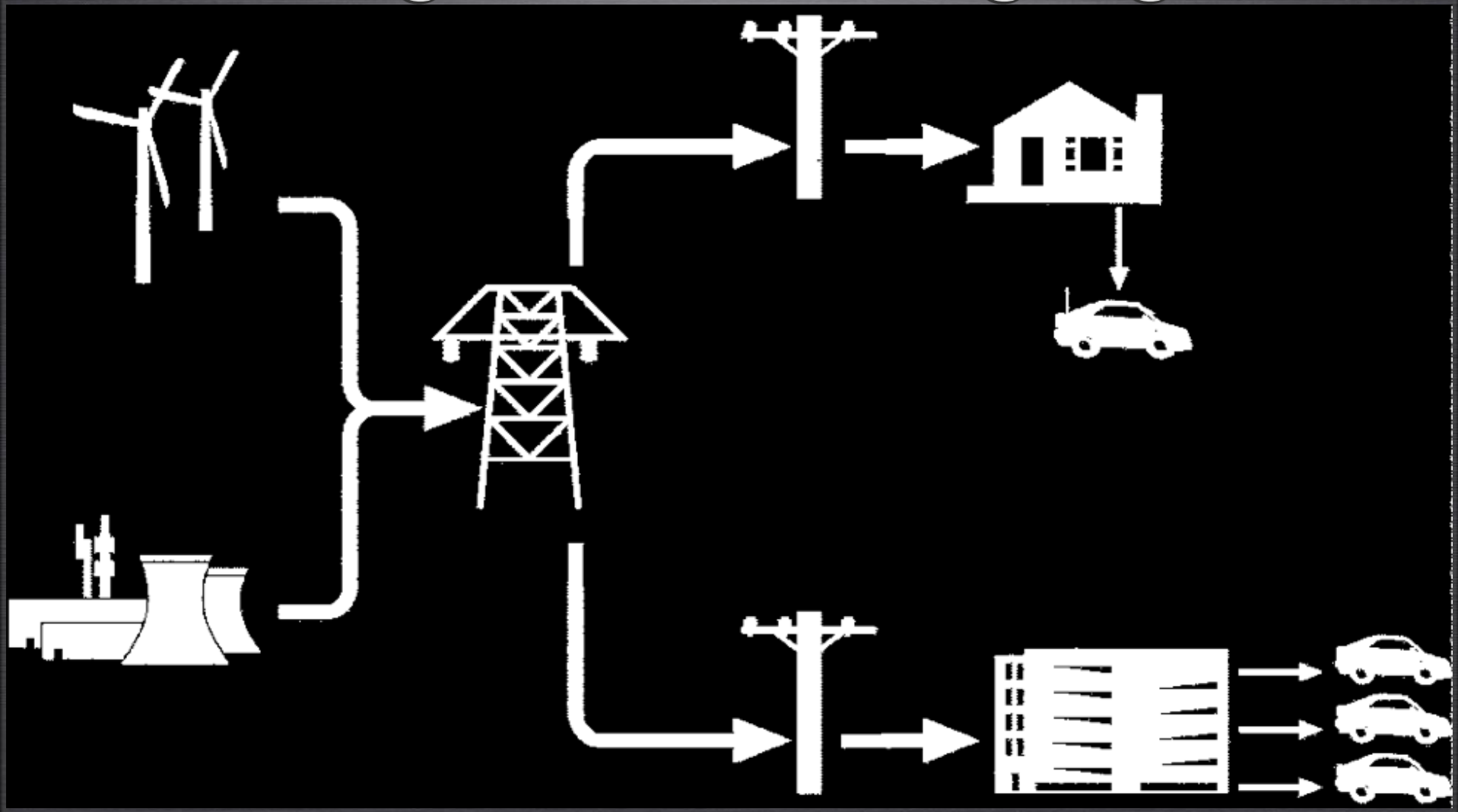
Washington, DC | 12 June 2011

Electric Vehicles

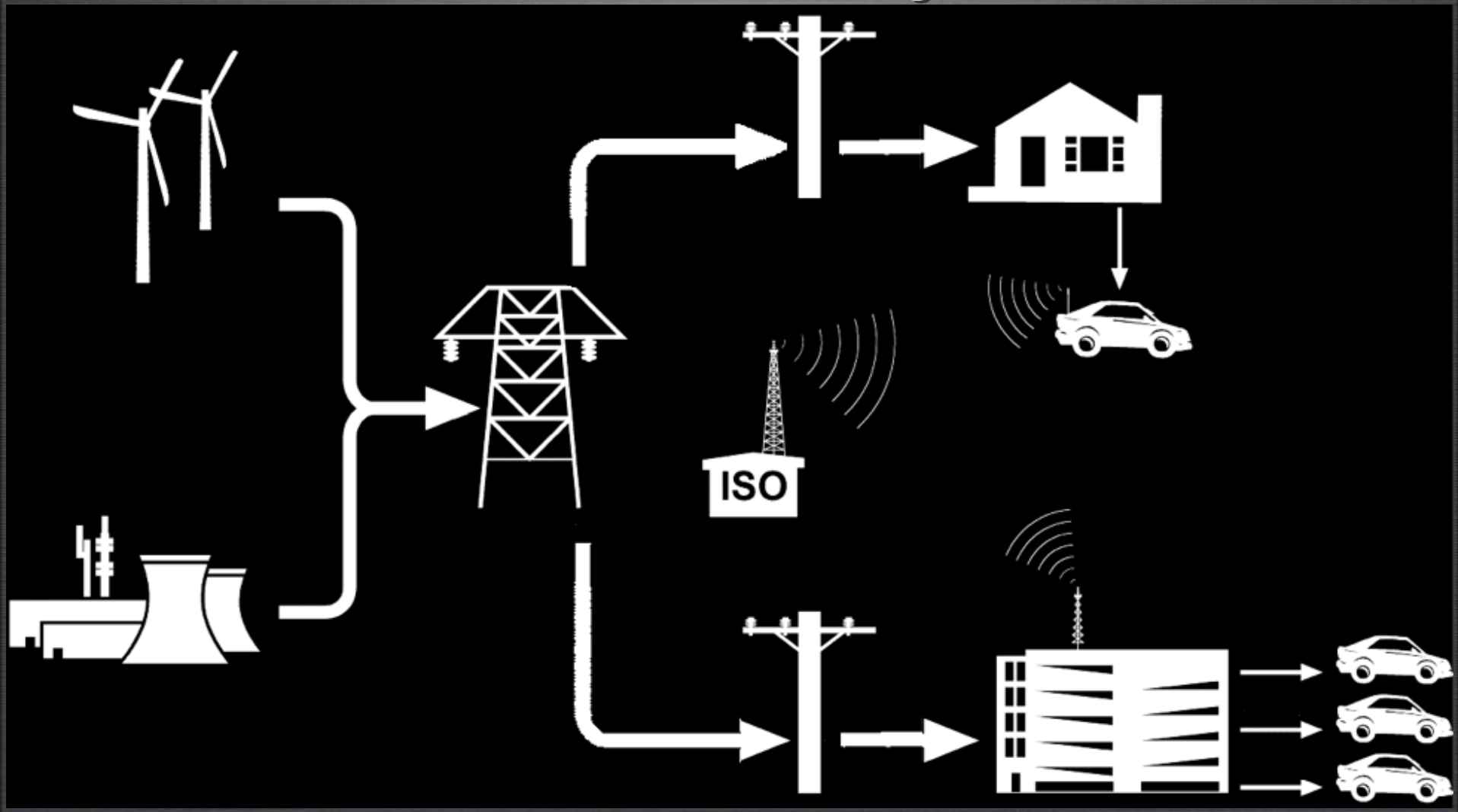
- Electricity as a fuel for the light vehicle fleet
- UD addition: Vehicle to Grid power (V2G), reverse flow from charging
- UD research: Create the **Grid Integrated Vehicle** (GIV), then operate, permit, and test it
- How does electricity as a fuel change the electric system?

The Grid-Integrated Vehicle, with Vehicle-to-Grid power

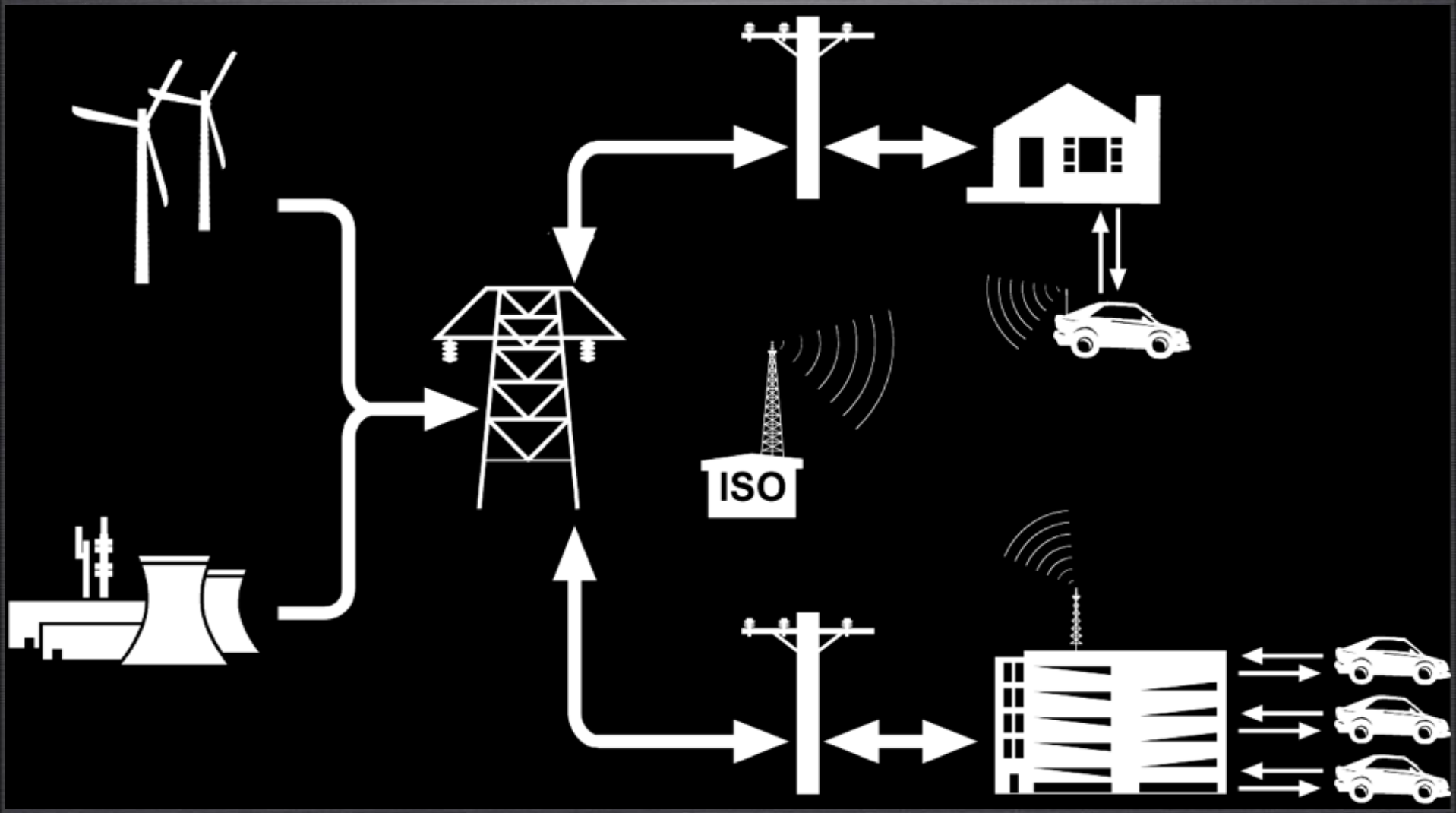
Plug-in for charging



GIV: Control by Grid



GIV+V2G: 2-Way Power Flow



Vehicle Aggregation Server

Design of Aggregator

- Provides a single, large, stable and reliable power source
- TSO does not see details of single cars, only sees aggregate
- Aggregator bids capacity in TSO market
- Dispatches dispatch requests to vehicles
- Reports actual power dispatched


pjm
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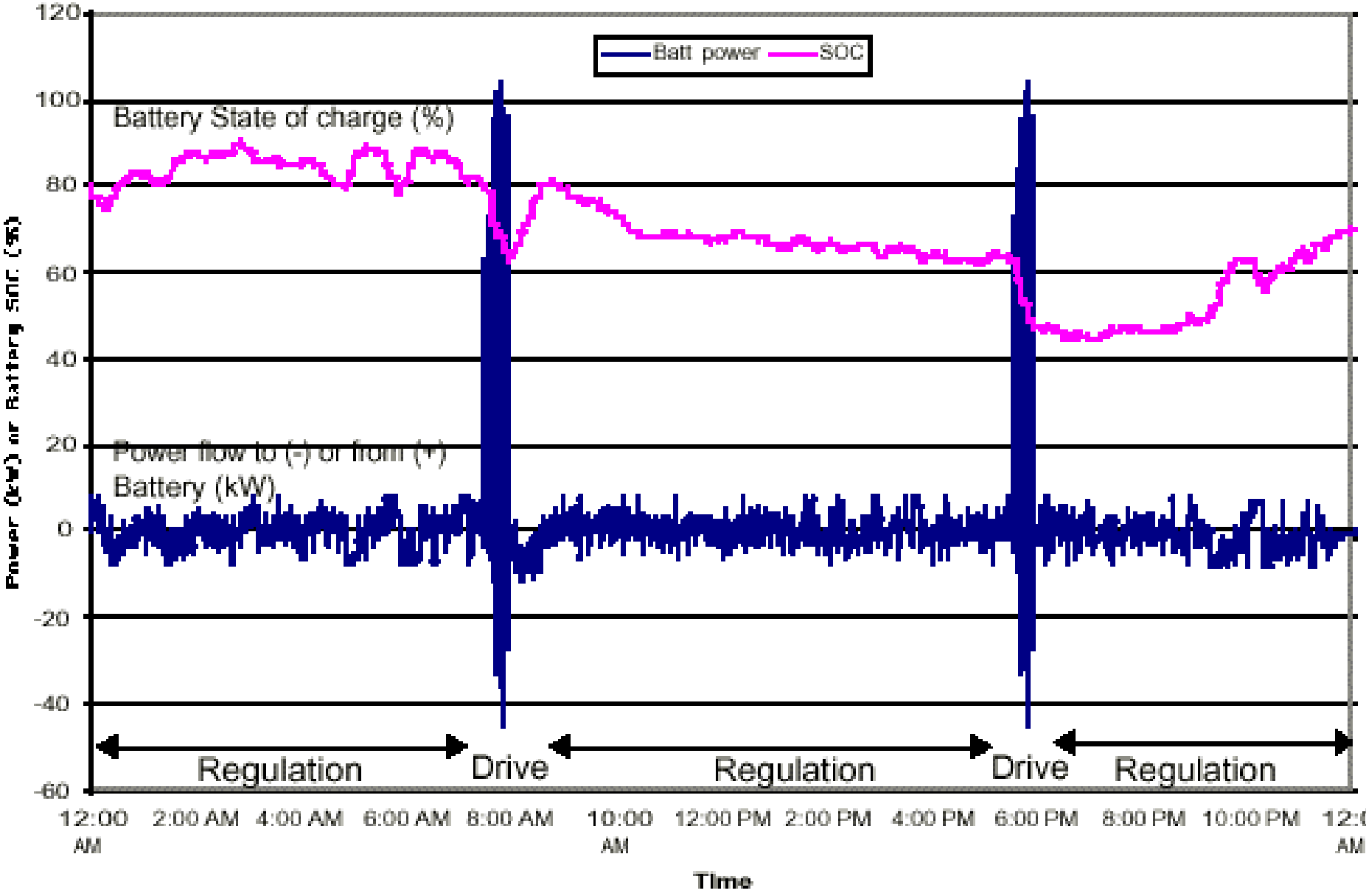
COM 1
COM 0
POWER
RUN
STAT
CHINOOK

Demonstration

- Seven vehicles in Delaware
- Each capable of up to 19.2 kW to or from power electronics (versus most OEMs at 3-4 kW charge only)
- When plugged in, register with server and offer capacity

Regulation, drive, regulation, drive



Results: Aggregator

Vehicle to Grid -- Coalition Server
University of Delaware

Coalition Status

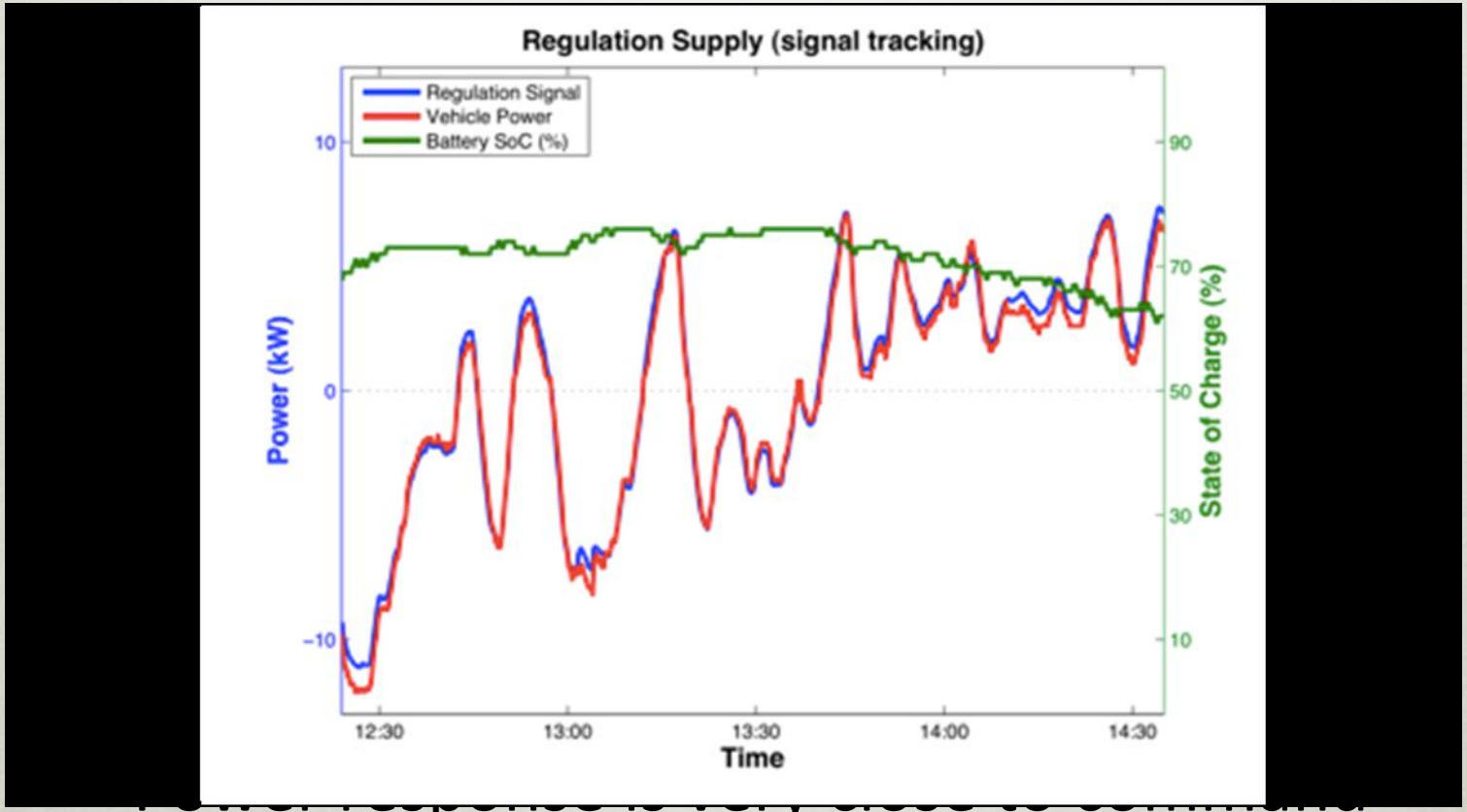
ISO	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Number of Cars
PJM	49.37	49.37	-14.80	-15.81	104.30	35.70	4
CAL-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0
Simulated-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0

Hide Charts | CAL-ISO | Simulated-ISO | PJM

Individual Vehicle Status

Car Name	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Miles	Volts (V)	Amps (A)	Monthly Credit ($)
UD-296	0.00	0.00	0.00	0.00	29.05	5.95	91.30	211	22.5	33.17
UD-170	11.23	11.23	-3.36	-3.95	12.60	22.40	39.60	234	16.9	76.31
DEState5205	10.70	10.70	-3.21	-2.05	33.25	1.75	104.50	214	9.6	21.73
DEState0000	17.36	17.36	-5.21	-5.70	31.50	3.50	99.00	248	23	24.59
UD-210	10.08	10.08	-3.02	-4.09	26.95	8.05	84.70	210	19.5	23.38

Results: Very fast response



signal.

- Far higher fidelity than any rotating equipment.

Why do GIV and V2G make sense?

Basic GIV/V2G Math

- US car used 1 hour/ day, parked 23 h/ d
- Drive train output = 100 kW
  - Practical power via US grid = 10 - 20 kW
- Cars as significant power capacity? Compare:
  - US generation ~1000 GW, avg. load ~450 GW
  - US light vehicles: 200 million
  - At 15 kW/ vehicle: 3,000 GW
    - **Cars: 3x generation, 6x average load**

Useful energy storage?

- Storage at the low-voltage end of the distribution system
- 15 kW & 30 kWh means ~1 hr discharge thus capacity markets, not energy
- Second use of customer equipment, thus capital costs are controls
- Need to aggregate many small storage units to get utility-scale power for TSO

Capital Cost of Distributed Capacity and Storage

- Capital cost is on-board intelligence plus communications, now ~$400
- For example, an EV with 15 kW, 30 kWh
- Capacity cost: $27/ kW
- Storage cost: $13/ kWh

Why high-power plug

- Should be 12 - 20 kW, not 2-6 kW
- Should be 208 or 240 VAC, not 110 V
- User convenience: last minute charge or roadside recharge @a mile-a-minute
- Capacity markets: Value of grid service proportional to kW
- Renewables planning: High penetration renewables needs high capacity per car

Power for recharge: Consumer value > Cost

Charge Time	GV Class	EV Class	Incremental device cost	Strategy for charger engineering
10 hours	$0	$0	(base)	110 VAC 12 A charger on board
5 hours	$4,720	$971	$600	208/240 VAC and larger components in charger for 4 kW
1 hour	$5,900	$7,626	-$800	Use drive train to charge, 19 kW
10 min.	$6,490	$11,093	$50,000	Station DC charger at 150 kW

Value per Vehicle

10 –Year Present Value V2G Revenue Potential

Assumptions: 80% availability, Reg. $40/ MW-h, Spin. $10/ MW-h, 7% discount rate, example calculations

Sequence of Markets

- High-value markets, are ancillary services (A/ S)
  - Frequency regulation
  - Spinning reserves

Sequence of Markets

- Later -- larger markets, lower value per kW
  - Defer upgrades to distribution feeders, transformers
  - Peak load reduction, valley filling
  - Power factor correction
  - Balancing wind, reducing ramp rate
  - Shifting solar peak to load peak

Interconnect Policy

Permitted by Load-Serving Entity (local utility)

City of Newark Generator Interconnection Application -Short Form

(For Use with Generators 25 kW or Less)

An applicant (Generator Owner) makes application to the City of Newark to install and operate a generating facility of 25kW or less interconnected with the City of Newark utility system.

Section 1. Applicant Information

Name: UNIV OF DELAWARE

Mailing Address: 222 S. CHAPEL

City: NEWARK State: DE Zip Code: 19716

Facility Location (if different from above): 401 Wyoming Rd

Telephone (Daytime): Area Code 302 Number 831-4907 (Evening) Area Code 302 Number 893-2148

City of Newark Electric Account No.: 08000002497-00 Pole Number: _____

Section 2. Generator Technical Information

NEM – Net Energy Metering

Is Generator powered from a Renewable NEM Qualifying Energy Source: [X] Yes [ ] No

Type NEM Qualifying Energy Source (if applicable): [ ] Solar [ ] Wind [ ] Hydro [X] Electric Vehicle

Generator (or solar collector) Manufacturer, Model Name & Number: AC Propulsion eBox (Battery System) Output Power Rating in kW: 120 kW

Inverter Manufacturer, Model Name & Number (if used): AC Propulsion AC-150 Rating in kW: 19.2 kW

NEWARK DELAWARE

delmarva power

Permitted by Load-Serving Entity (local utility)

Will a generator disconnect device, accessible to the City of Newark, be installed?: ☐ Yes ☒ No

If the Generator Owner elects not to install a manual disconnect device accessible to the City of Newark, the Generator Owner assumes all risks and consequences when a service meter must be "pulled" to disconnect the generator thereby also interrupting all utility electric service to the Customer site.

Will an automatic transfer switch be used? ☐ Yes ☒ No

Supply specifications for the transfer switch showing UL listing and "Break before Make" contacts.

Section 3. Generator/Equipment Certification

~~Generating systems that use utilize inverter technology must be compliant with IEEE 929 and Underwriters Lab. UL 1741.~~ **By signing below, the Applicant certifies that the installed generating equipment meets the appropriate preceding requirement(s) and can supply documentation that confirms compliance.** *

Signed (Applicant): _____ Date: 1/8/09

* Documentation has been provided to the City certifying that the AL-150 inverter meets IEEE 1547 standards.

"meets IEEE 1547 standards"

Law to codify interconnects, net metering for V2G

SPONSOR: Sen. Simpson & Rep. Kowalko
Sen. McDowell; Rep. Hocker

DELAWARE STATE SENATE
145th GENERAL ASSEMBLY

SENATE BILL NO. 153

AN ACT TO AMEND TITLE 26 OF THE DELAWARE CODE RELATING TO CUSTOMER SITED ENERGY RESOURCES.

BE IT ENACTED BY THE GENERAL ASSEMBLY OF THE STATE OF DELAWARE (Two-thirds of all members elected to each house thereof concurring therein):

Section 1. Amend §1001, Title 26 of the Delaware Code by adding two new definitions reading as follows, and renumbering existing definitions alphabetically.

"(1) 'Aggregator' means any person or entity who contracts with an electric distribution company, electric supplier or PJM Interconnection (or its successor) to provide energy services, which facilitate battery storage systems for grid-integrated electric vehicles and related technologies.

(14) 'Grid-Integrated Electric Vehicle' means a battery-run motor vehicle that has the ability for two-way power flow between the vehicle and the electric grid and the communications hardware and software that allow for the external control of battery charging and discharging by an electric distribution company, electric supplier, PJM Interconnection, or an aggregator."

Define:

Aggregator

Grid-integrated electric vehicle

law to codify interconnects

Section 2. Amend §1014, Title 26 of the Delaware Code by adding a new subsection to read as follows:

(g) A retail electric customer having on its premises one or more grid-integrated electric vehicles shall be credited in kilowatt-hours (kWh) for energy discharged to the grid from the vehicle's battery at the same kWh rate that customer pays to charge the battery from the grid, as defined in (e)(1) of this section. For electric customers with time of use rates, the kWh rate for charging and discharging shall be the rate in effect when charging or discharging occurs. Excess kWh credits shall be handled in the same manner as net metering as described in (e)(1) of this section. To qualify under this subsection, the grid-integrated electric vehicle must meet the requirements in (d)(1)a., (d)(1)b. and (d)(4) of this section. Connection and metering of grid integrated vehicles shall be subject to the rules and regulations found in (e)(2), (e)(3), and (e)(4) of this section.

Net metering for V2G

Net is at rate at time of use

Interconnection requirements, etc same as distributed renewables

Patents

Patents

- Patent Applications, 2007-2010:
  - U.S. Patent Application Publication Nos. 2007/ 0282495 A1 "System and Method for Assessing Vehicle-to-Grid (V2G) Integration" filed May 2007 (UD; Kempton and Tomic)
  - U.S. Patent application publication No. "Hierarchical Priority and Control Algorithms for the Grid-Integrated Vehicle", filed March 2009, (UD; Kempton)
  - Three US and PCT applications in 2010, Electric Vehicle Station Equipment for Grid-Integrated Vehicles; Electric Vehicle Equipment for Grid-Integrated Vehicles; Aggregator Server for Grid-Integrated Vehicles. Filed Sept 2010 (UD; Kempton and co-inventors)
- Signed licenses for VSL and Aggregator, in license negotiations for EVSE and more VSLs

So even when your car is parked, it is working earning money for you

Net Results of DOE-Funded R&D

- Fully-functioning GIV with real-time dispatch by grid operator
  - Concept proven and running
  - Licenses to commercial entities
  - Manufacturing vehicles & components
- Use J1772 for signaling without pinout change
- Laws passed; rule agreement
- Measured value of EV attributes and range needs

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More information:

www.udel.edu/V2G

www.magicconsortium.org