IEEE Future Networks

Networked Electricity

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BERKELEY LAB

Image from Eric Brewer talk
“**Energy in the Developing World**”
January 14, 2010
(LoCal Retreat)

Photo: Matthew Kam, TIER
School near Lucknow, India

Features we should demand for Power Distribution

- "Plug-and-play" operation
  - End-use devices
  - Local generation
  - Local storage
- Improved safety
- Arbitrary power topologies – inter-building links
- Fine-grained management of constrained supply
  - Optimal use of distributed storage
- Greater reliability – and lesser
- Universal technologies
- Enabling optimal operation with a local price
- Security / privacy
- Greater efficiency with Direct DC

“Local Power Distribution”

- “Local” – within a building (or campus)
  - Not involving utility grid
- “Power Distribution”
  - “Technology / infrastructure that moves electrons from devices where they are **available** to devices where they are **wanted**”

Local Power Distribution is a
network model of power

Grid terminology

- **Microgrid** Capability

  "… a group of interconnected loads and distributed energy resources …that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to **operate in both grid-connected or island-mode**." *(DOE Microgrid Exchange Group)*

  Implies must connect to utility grid; CIGRE C6-22 defn. similar

- **Nanogrid** Simplicity

  "A **single domain of power**; single voltage, frequency (if AC), reliability, quality, capacity (power), **price**, and administration. Storage is internal to a nanogrid." Generation forms its own nanogrid. *(Nordman, 2010)*

- **Picogrid** Singularity

  An **individual device with its own internal battery** for operation when external sources are not available or not preferred, and managed use of the battery. *(S. Ghai et al. in* e-energy 2013; *paraphrased)*

Telephony - then

- My childhood phone*

- Part of monolithic phone system
- Incapable of independent operation

Telephony – one future

- Digitize the past

- Slightly better version of old technology
- Still can’t do anything really new

Promised telecom future

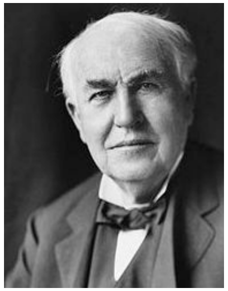
- Videophone - 1964 World's Fair (New York)

- Never happened
- Still point-to-point model

Telephony - now

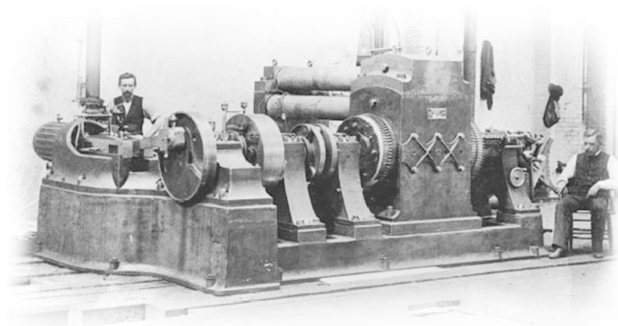
- Multiple fundamentally new technologies and paradigms

- Does many things impossible with old concept
- Highly useful even with no 'grid' connection
- Much more expensive than old telephony



137 … 888 years later

Generation | End use | Distribution



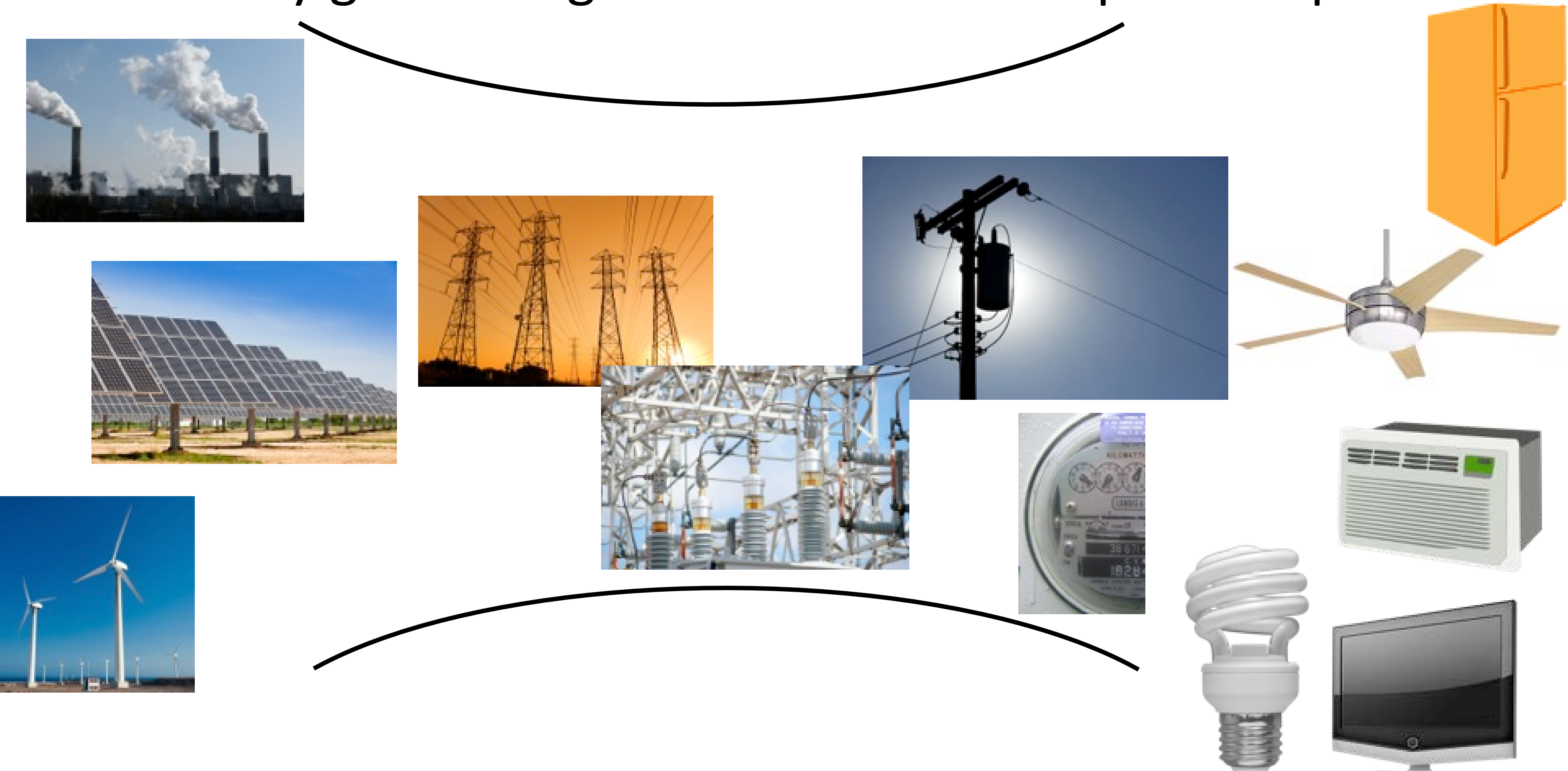




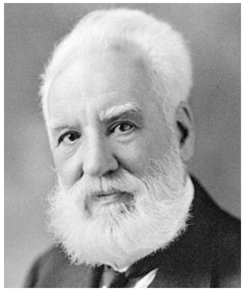


Traditional power distribution

"Unitary grid" - single undifferentiated "pool" of power



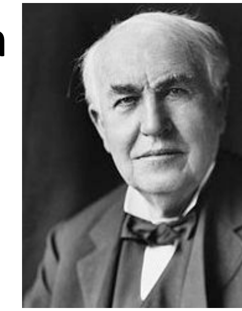
- Buildings and all devices part of the pool



Bell

Communications and Power

Edison



- Phone system and utility grid invented about same time (circa 1880)
  - – Synchronous – highly coupled
  - – Unitary – to end points – centrally managed
  - – Organizations conservative - regulated
  - – Technology advances slowly
  - – Local variations in technology - minor
  - – One mode of operation

Paradigms

Unitary	*Networked*
Old phone system	**Internet**
Utility grid	**Network model of power**
19^{th} century	$20^{th}/21^{st}$ century
Centralized	Distributed
Analog	Digital
No storage	Storage widespread
Tightly coupled	Loosely coupled
Entangled technology	Isolated technologies
Custom / Expensive	Commodity / Cheap
…..	…..

Need paradigm shift

Power & information distribution

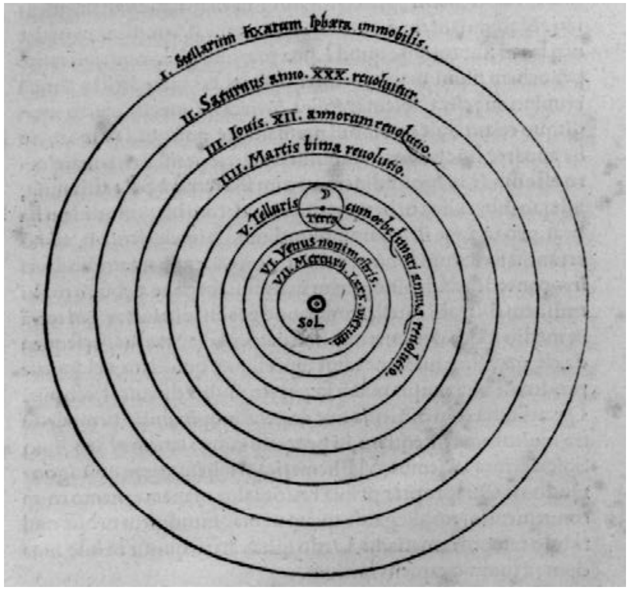
"Technology / infrastructure that moves data / electrons from devices where they are available to devices where they are wanted"

All bits (packets) different; all electrons same

- Need a **fundamental mechanism** for a network model
- Communications: understand system topology (addressing) and move data accordingly
  - Data routing is how bits know where to go
- Power: balance supply and demand
  - Price is how electrons know where to go
    - Routing power makes no sense

Location, quantity, timing

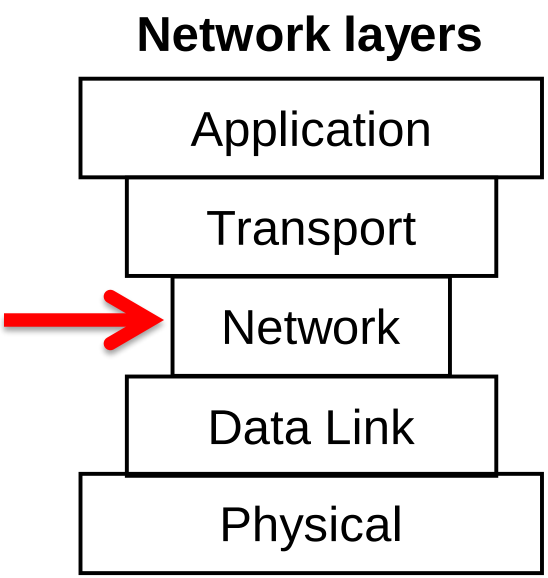
Paradigm changes

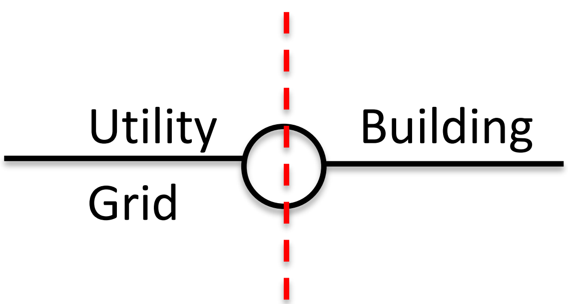


Indications for network model of power

- Use digital technology everywhere
- Use storage to decouple/desynchronize
  - Distribute widely for stability, reliability
- Diverge technology in buildings from backbone technology
- Derive inspiration from electronics/IT — not from utility grid
- SIMPLICITY – complexity

Layered models – (e.g. OSI Model)





- Prices down; meter readings up
- Electrons either direction

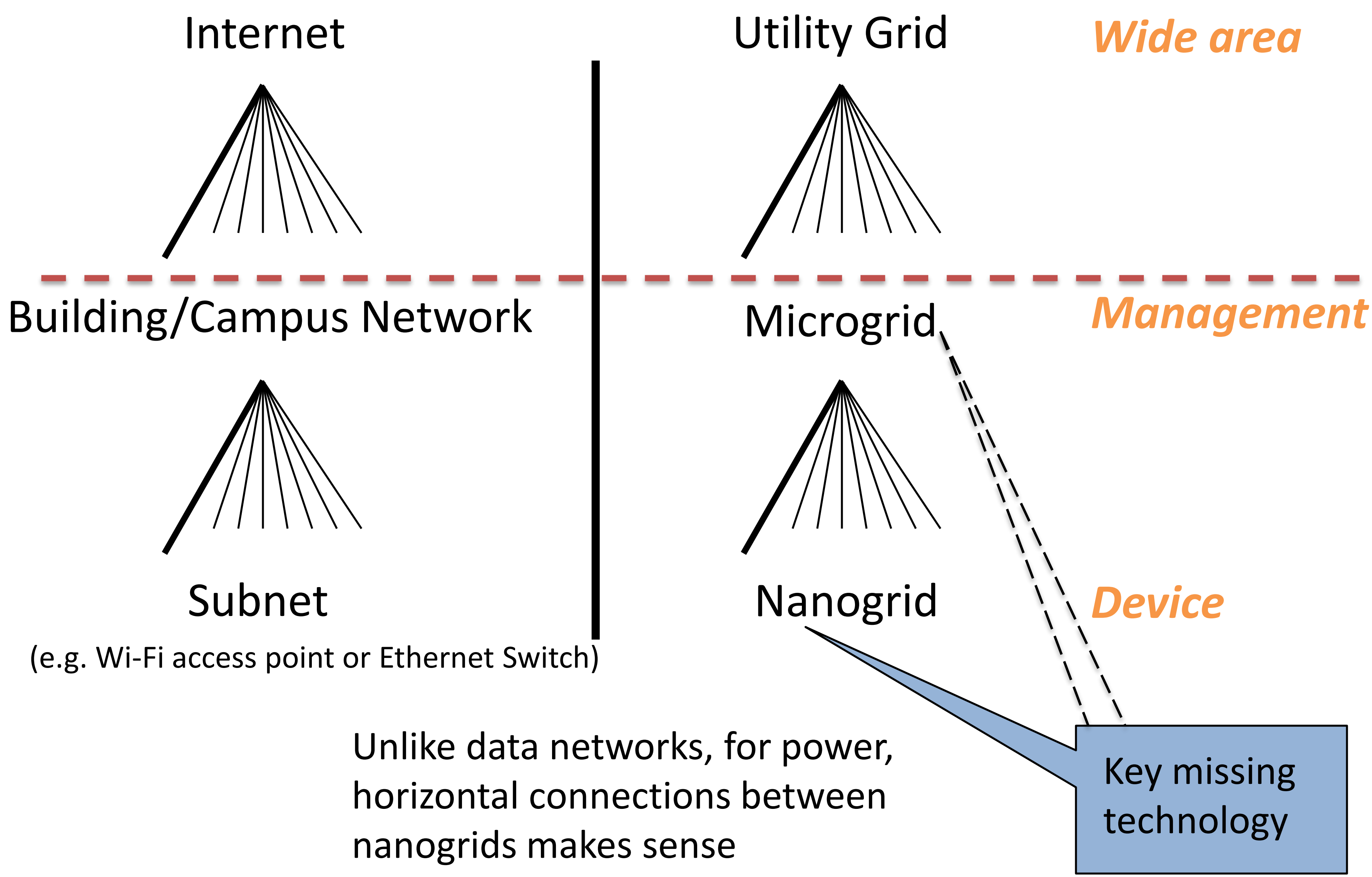
- Narrow waist in layering **isolates complexity** – facilitates interoperability
  - Buildings need three layered models
- Conventional network communication
  - Application and physical layers
- Electricity / utility meter
  - Utility grid from building
- Device internal Network Power Integration
  - Power distribution distinct from functional control

Layered model for device operation for Local Power Distribution

Network Power Integration

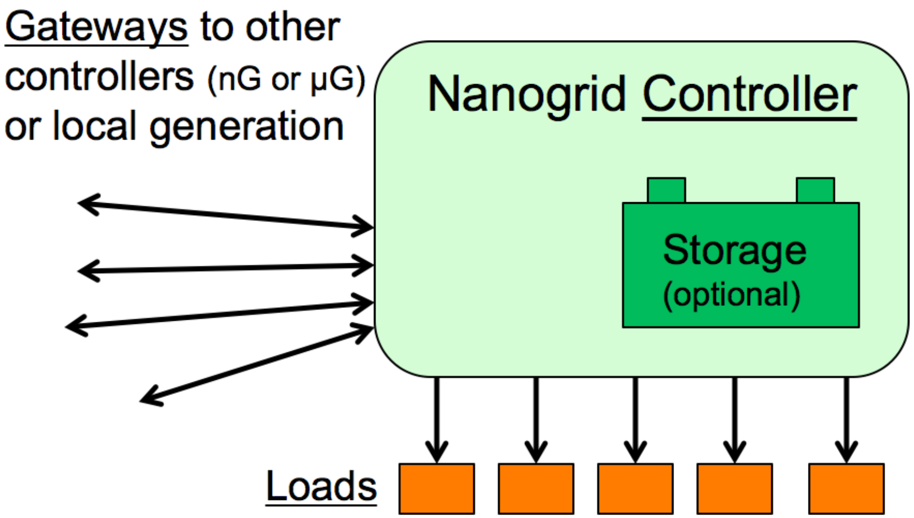
Network layers	NPI layers
Application	5. Functional coordination
Transport	4. Device discovery and events
Network	3. Internal integration — [Quantity, Price]
Data Link	2. Exchange within/between grids
Physical	1. Transport of electrons

Scaling structure — communications and power

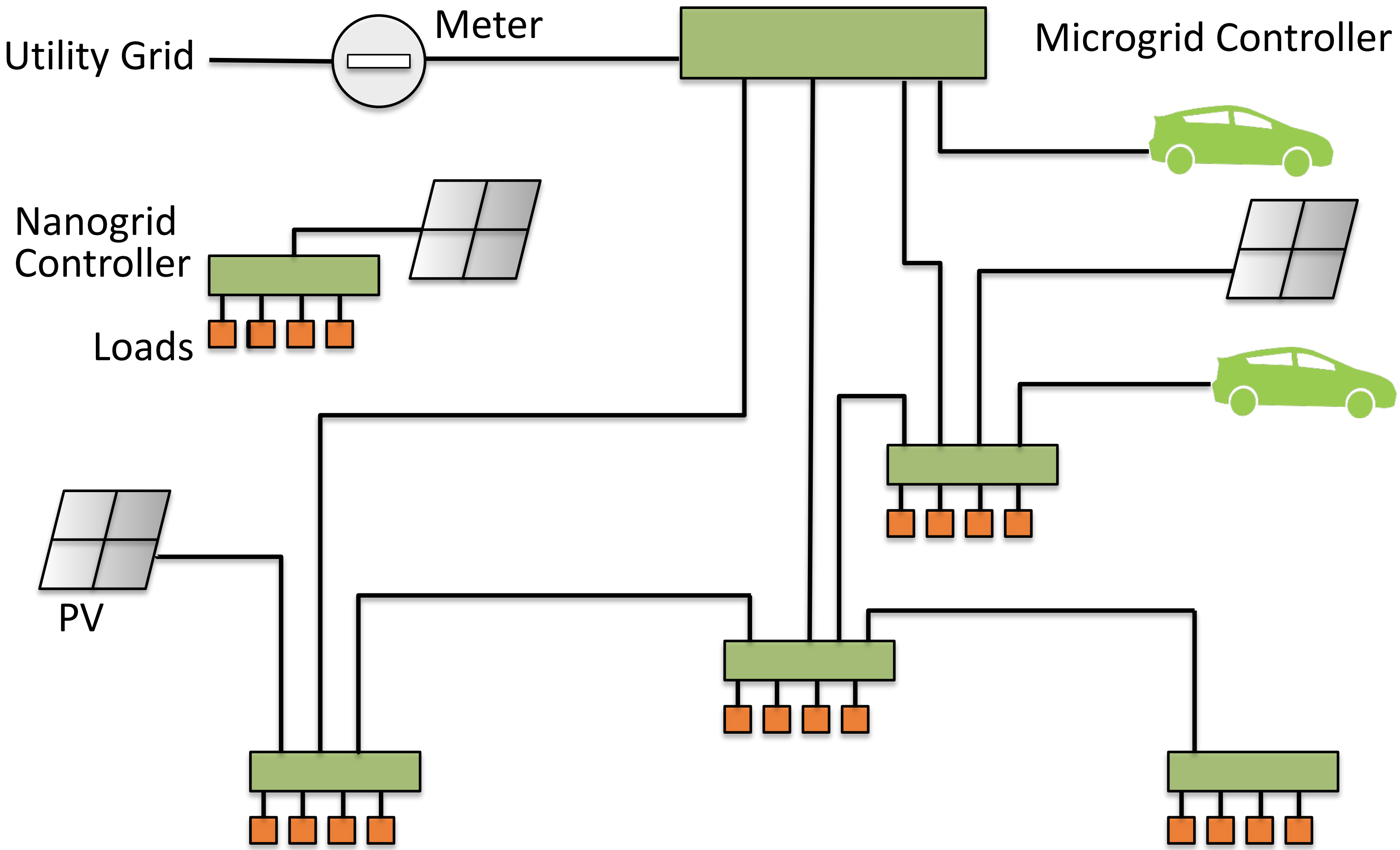


What is a Nanogrid?

- Smallest unit of power distribution
- Single physical layer (voltage; usually DC)
- Single domain: administration, reliability, capacity, and **price**
- Can interoperate with other local grids
  - Generation forms own nanogrid
  - Only two device types: grid controller and load
- In fully-functioning nanogrid, all links include communications
- Wide range in technology, capability, capacity



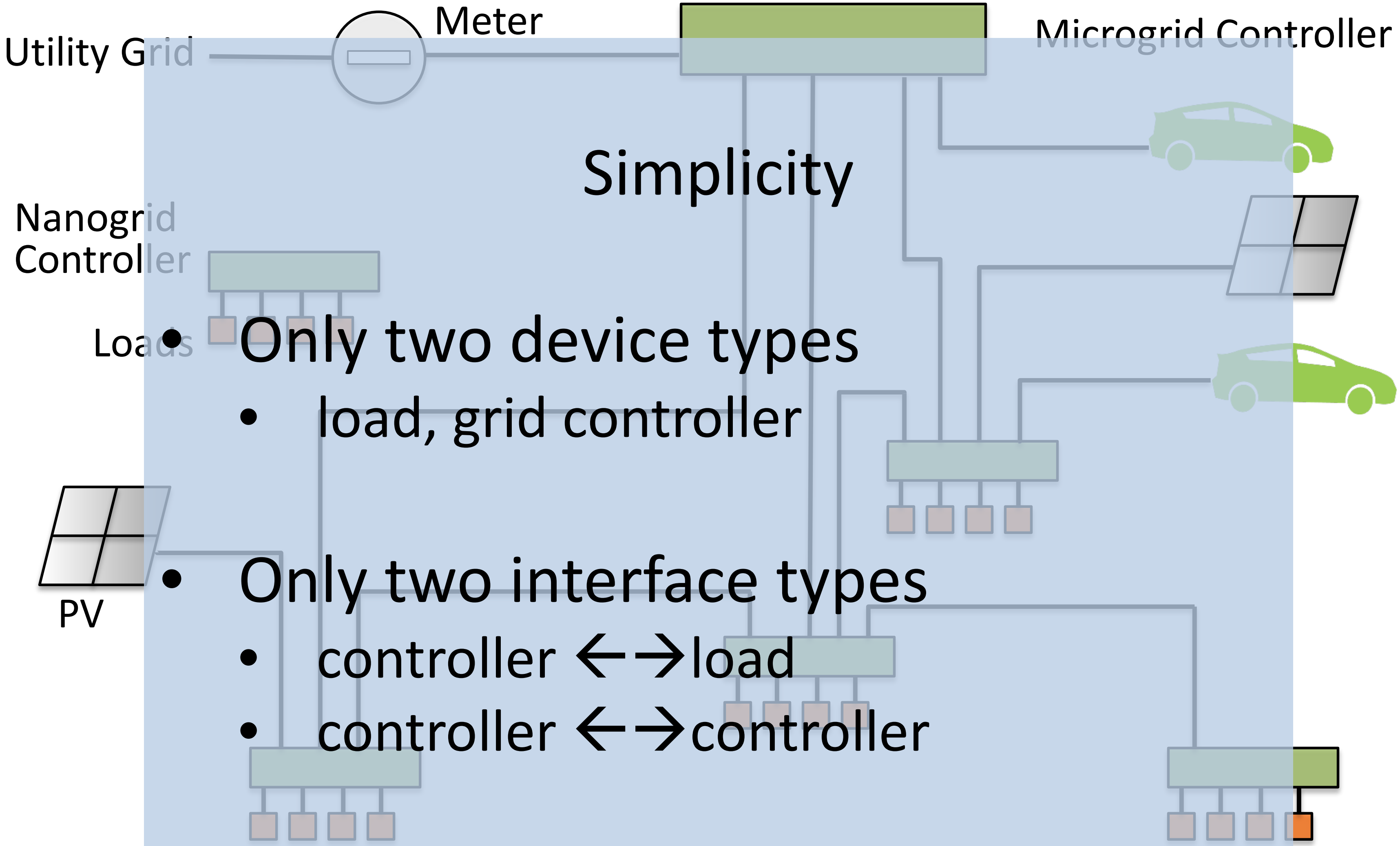
Example local grid network



All connections peer-to-peer and can be changed dynamically

Price is how devices know which way power should flow

Example local grid network



Simplicity

- Only two device types
  - load, grid controller
- Only two interface types
  - controller ←→load
  - controller ←→controller

All connections peer-to-peer and can be changed dynamically

Price is how devices know which way power should flow

Features we should demand for power distribution

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LPD provides these features

Myth of uniform power availability

- Electricity is <u>not</u> equally available across space and time
  - Has long been true within utility grid
    - "Locational Marginal Price"
  - Increasingly true within buildings
    - Local storage and/or generation, islanded grids, capacity constraints, combined heat-and-power, vehicles/mobile

- Technology we have today presumes uniform availability – **hence constant price**
- Dynamic pricing at meter a needed starting point
  - Grid can express preferences to customer

Reasons for differing local prices

- Differential buy/sell prices from utility
- Local valuation of carbon
- Losses from AC/DC or voltage conversion, battery losses, wiring losses
- Capacity constraints
- Off-grid operation – incl. mobile
- Battery management goals
- Local generation conditions (dispatch; co-gen)

Price always **current** price and a
non-binding **forecast** of future prices

Communication about power

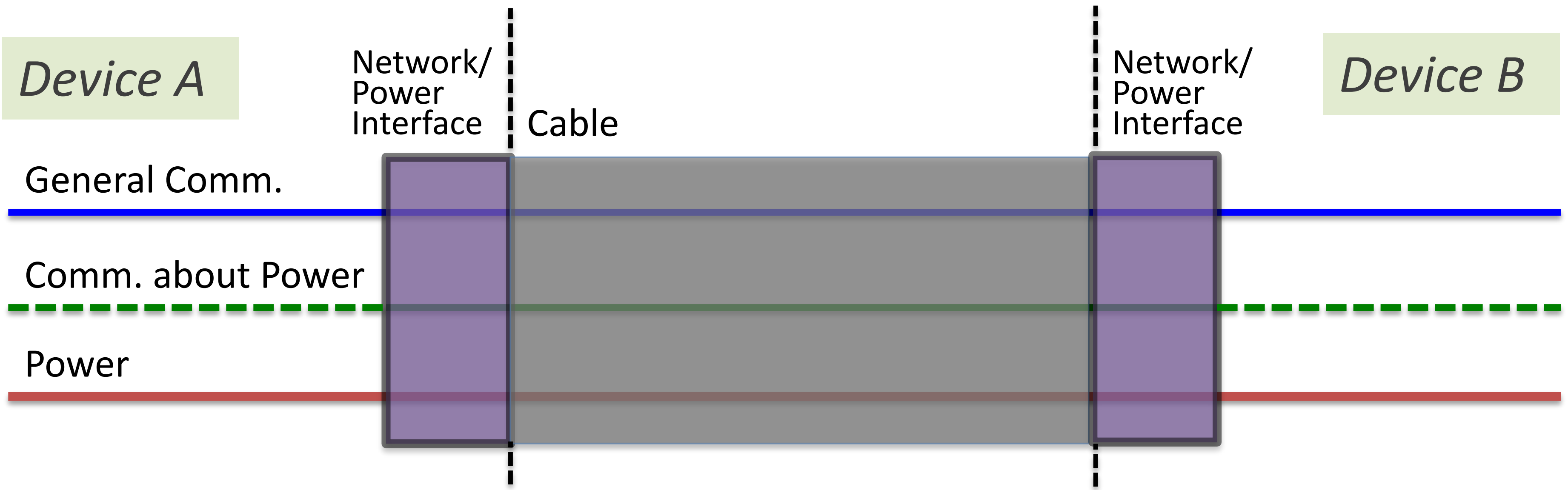
“Standard DC”

A method for transmitting DC power defined by a well-known technology standard, enabling plug-and-play interoperability

“Managed DC”

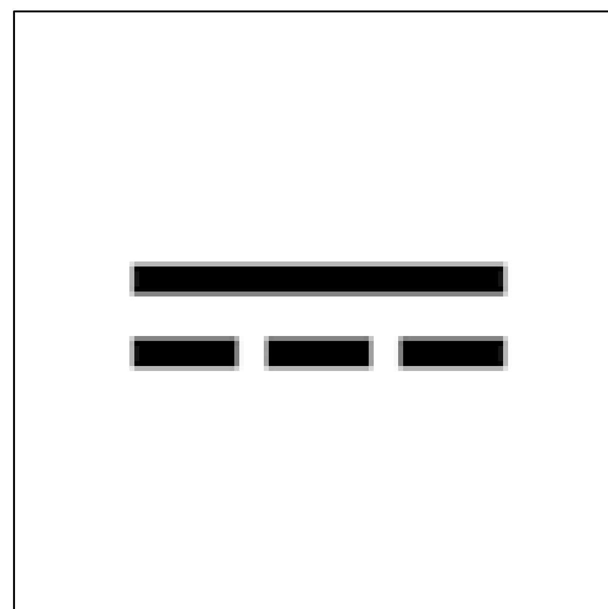
Standard DC technologies that include communications for managing power distribution within the power cable & connector

- Communications over power wires or adjacent wires
- Examples: PoE and USB



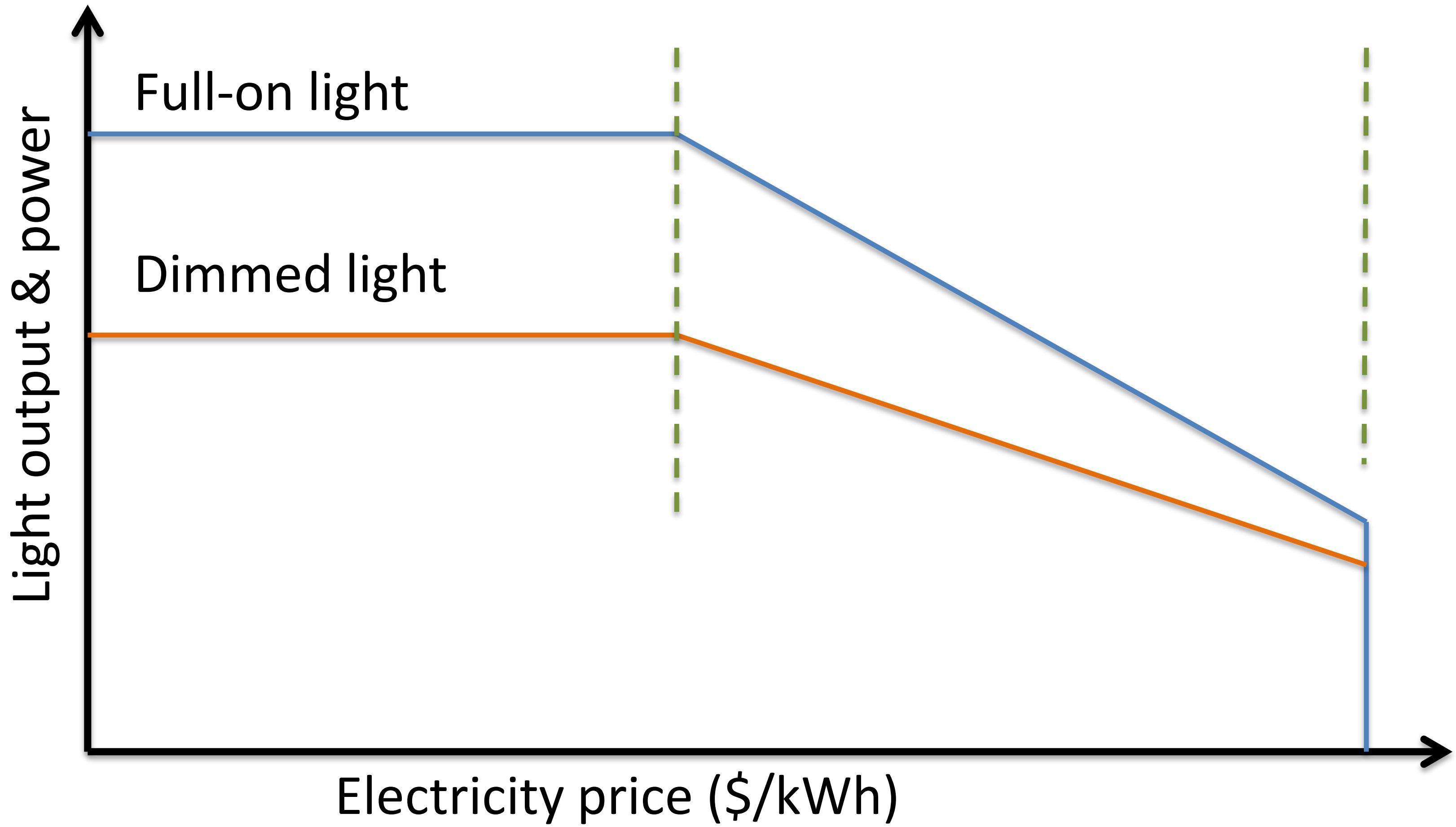
Link Technology for LPD

- USB and Ethernet <u>have</u>
  - Communications about power
  - 100 W per cable (HDBaseT; Ethernet 90W)
  - Bidirectional power (HDBaseT)
  - Power ‘hubs’ with integral storage
- USB and Ethernet <u>need</u>
  - Local price*
  - Controller-controller coord.
- Need to consider for each
  - Multi-drop capability



**Ethernet now has*

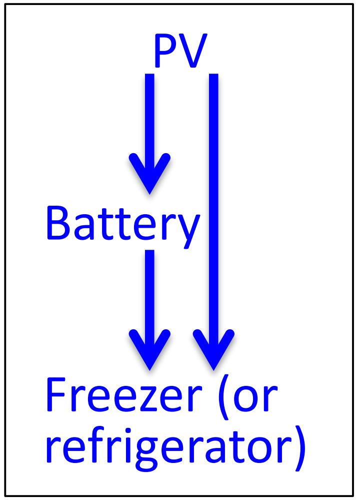
Example: Price-responsive light



Control algorithms can change at any time

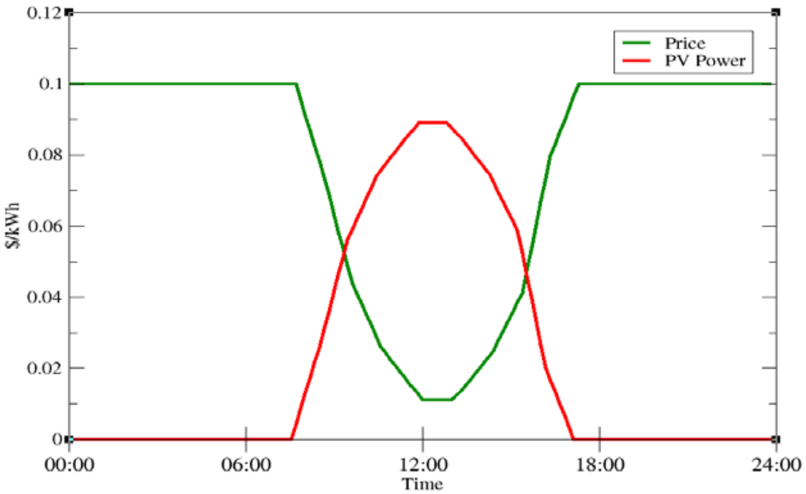
Example: Price-responsive freezer

- Off-grid context
  - Source, storage, end use



- Operation
  - PV → Price → Setpoint → Compressor

- Variable price created as inverse of PV output



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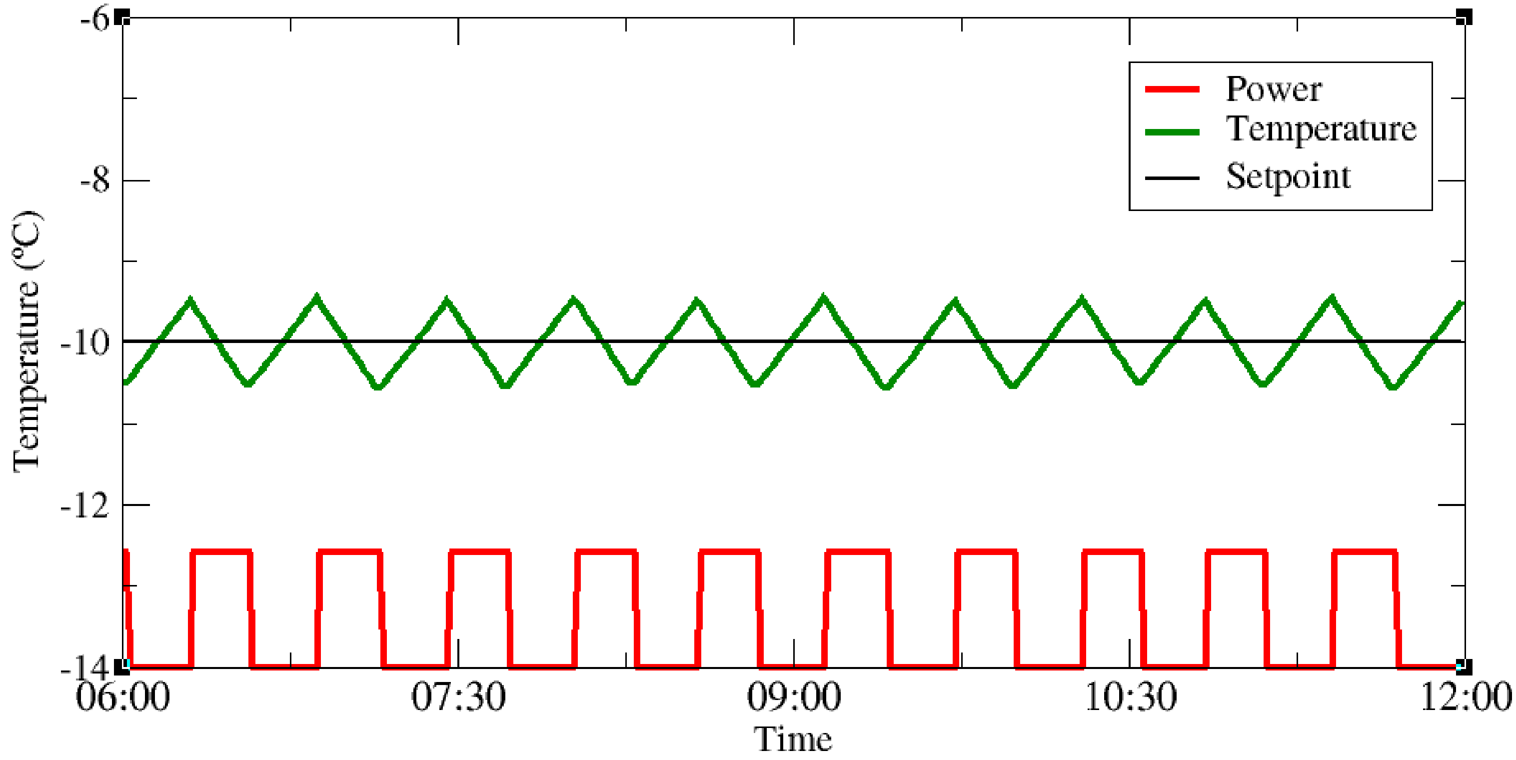
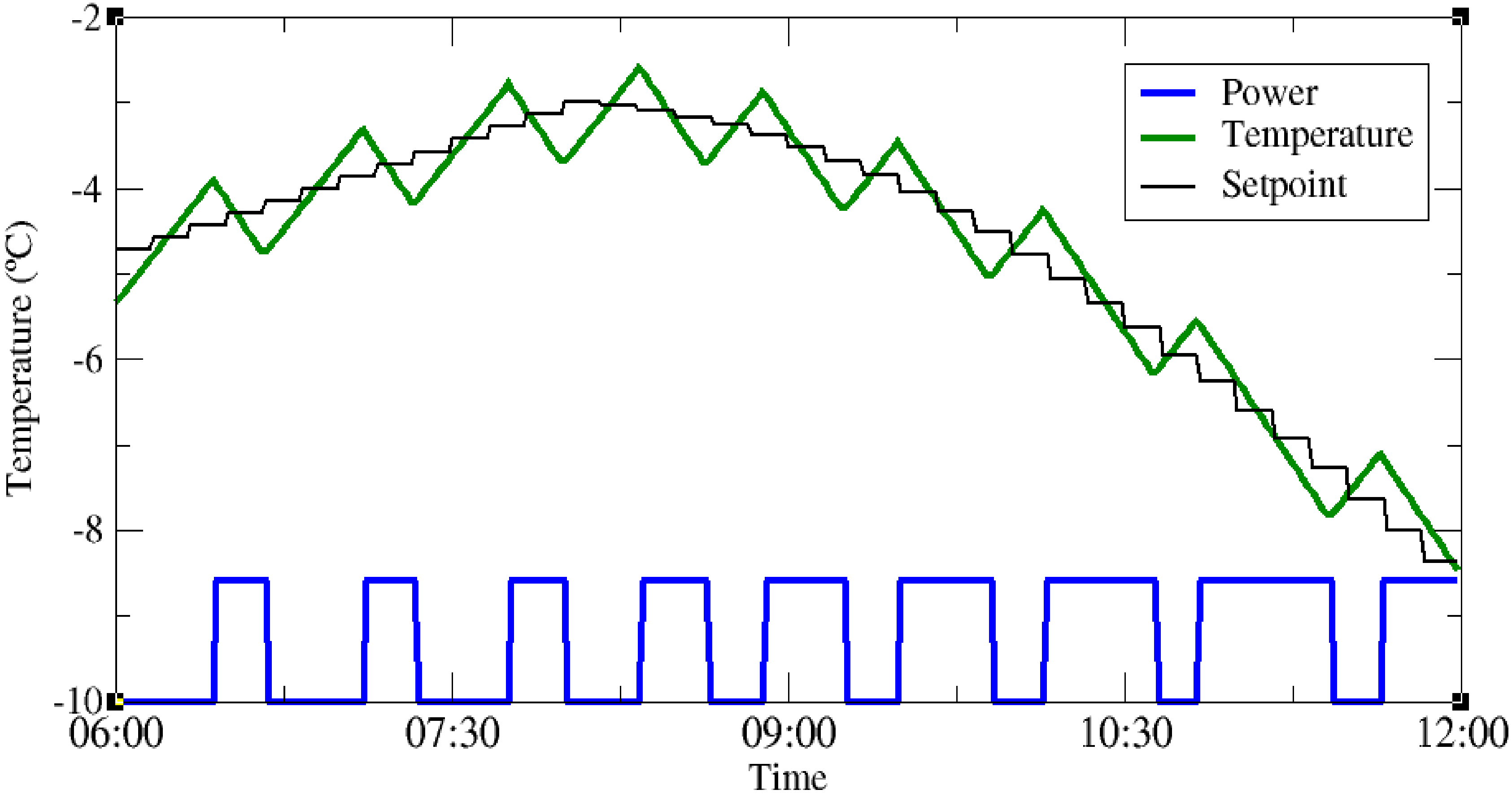
Freezer — Constant price



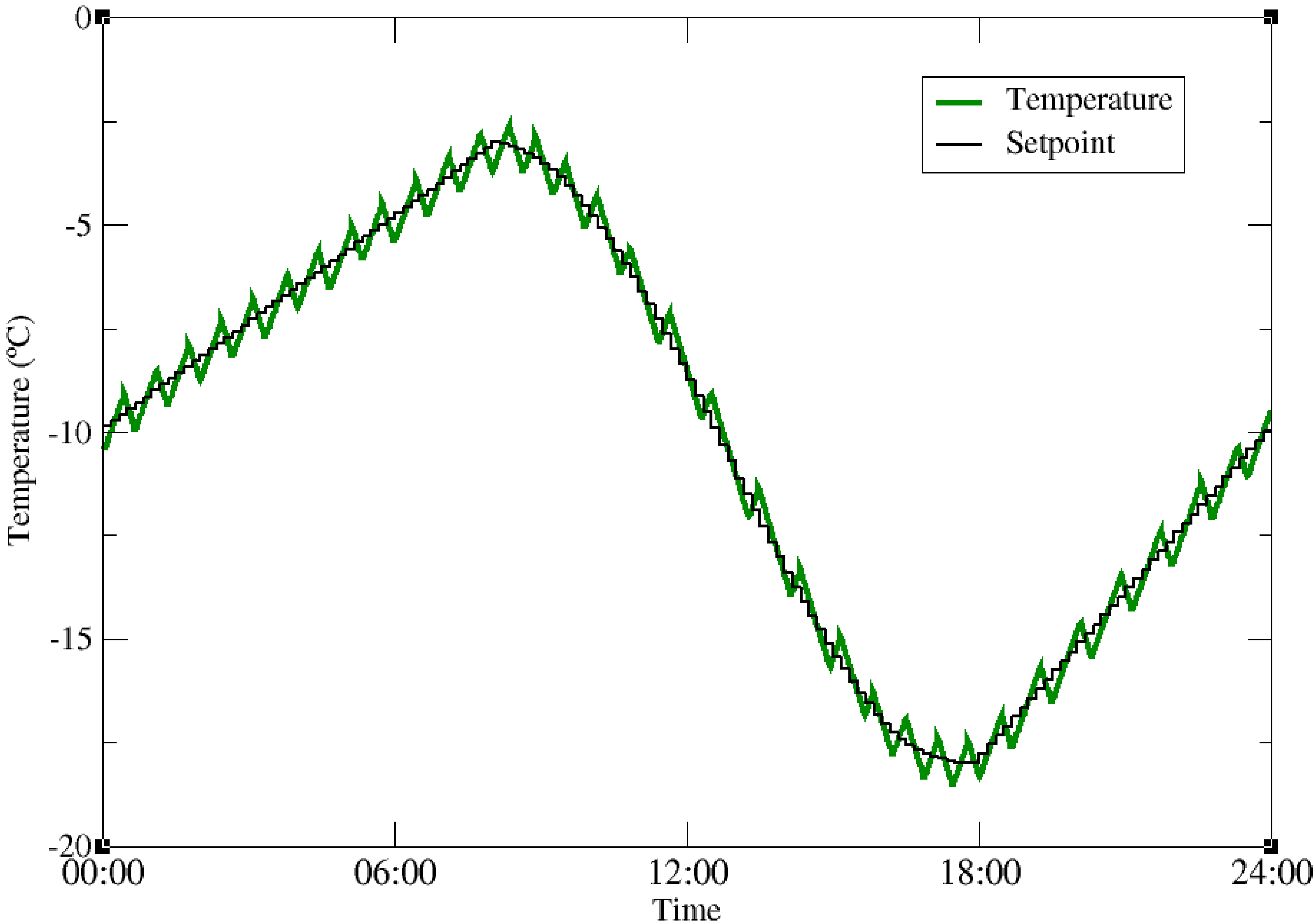
- Constant setpoint (-10 C)
- Compressor on-times and off-times about 20 minutes each
- Behavior never varies

Freezer — Variable price (6 hours)

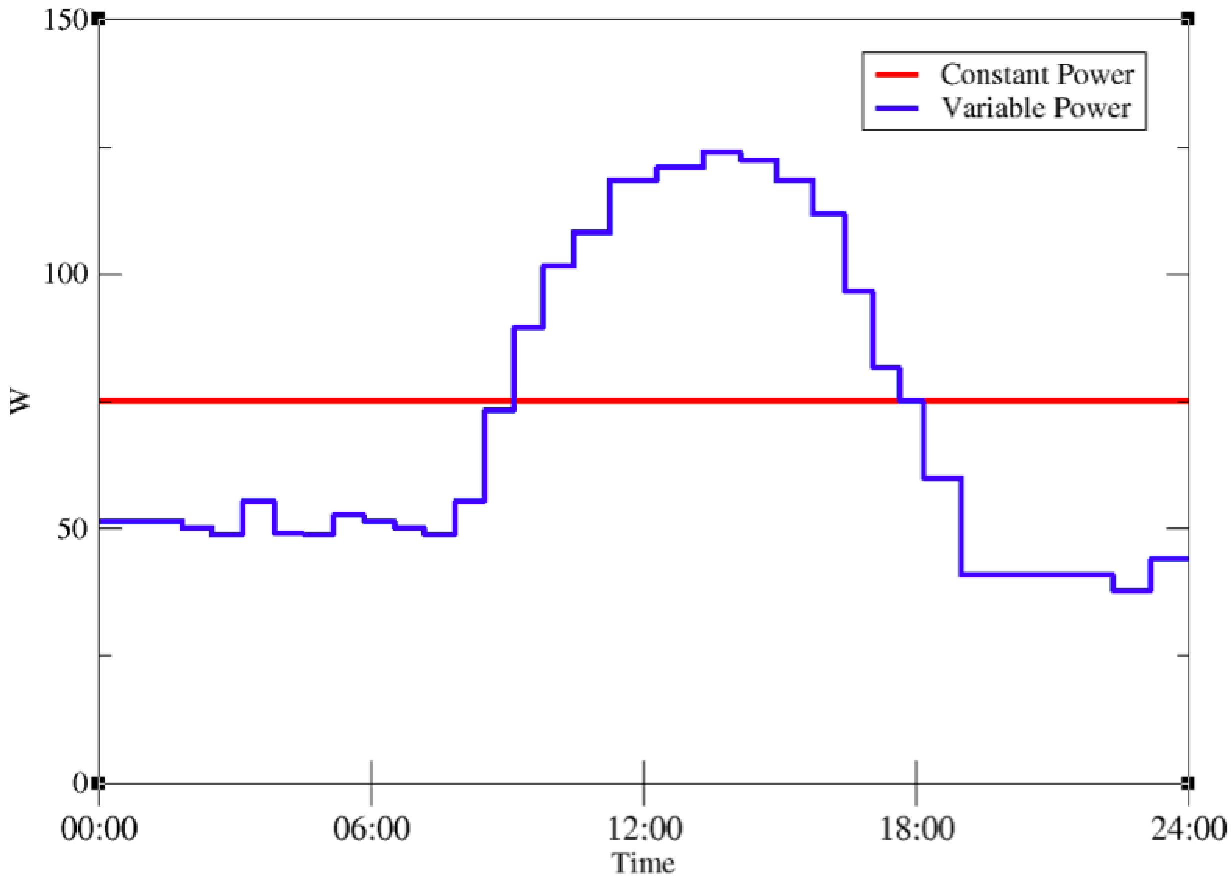


- Variable Setpoint (-3 C to -18 C)
- Variable compressor on-times and off-times
  - (10 minute minimum on-times)

Freezer — Variable price (24 hours)

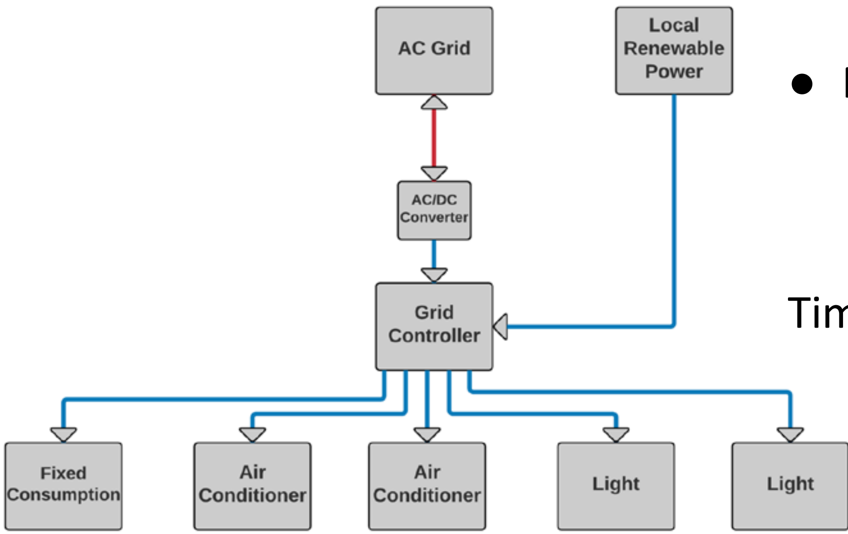


Freezer energy use
(average power per cycle)



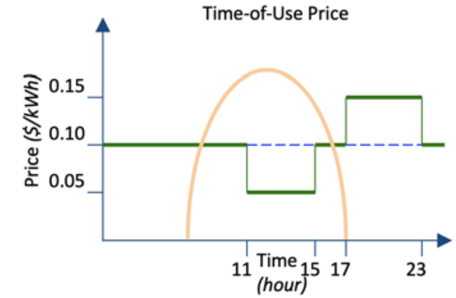
- Less energy used overall (More direct DC)
- Less PV
- Smaller battery
- Lower battery losses

Simulation Results - more devices

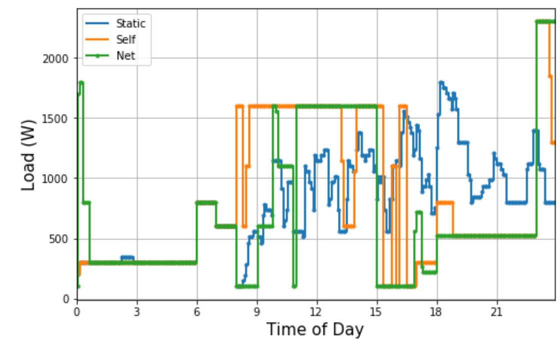


- Price at meter – 3 scenarios
  - Flat
  - TOU – net metering
  - TOU – self supply

Time-of-Use



Total - All Scenarios



- Storage - air conditioner and battery - shift load
- Lighting - dims

- Prices effective at shifting load to low-price times
- Net metering most effective at reducing energy and costs
- Self-supply uses more energy but reduces costs

	Static	Self Supply	Net Metering
Energy (kWh)			
Low - $0.05/kWh	-2.35	0.16	1.16
Medium - $0.10/kWh	4.23	7.35	3.89
High - $0.15/kWh	6.7	2.23	2.03
Total	**8.58**	**9.74**	**7.09**
Cost ($)			
Low - $0.05/kWh	-0.12	0.01	0.06
Medium - $0.10/kWh	0.42	0.73	0.39
High - $0.15/kWh	1.01	0.33	0.31
Total	**1.31**	**1.08**	**0.75**
Total – Export $0.00	**1.56**	**1.11**	**0.98**

"Total" cost - export paid at purchase rate
"Export $0.00" - export to the grid paid nothing

Communications Details

No fixed time-steps; No central clock; No central entity

Any message can be sent any time

Price

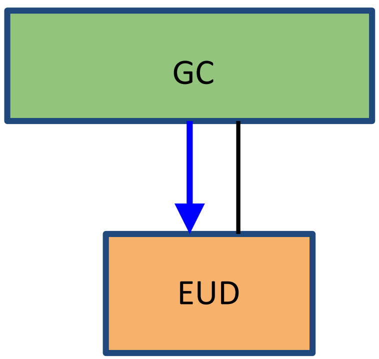
- `Price`: GC sends a price (incl. forecast) any time it changes *($/kWh)*

EUD: End-Use Device
GC: Grid Controller

GC <--> EUD (1-way power flow)

Power Allocation

- `Request`: EUD requests authority to consume up to *XX* W
- `Allocate*`: GC grants the EUD
  - full power request or partial grant or no power at all
  - *EUD may then consume any amount of power between zero and the granted amount*

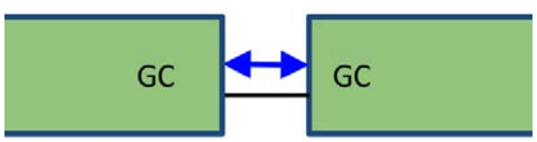


GC <--> GC (2-way power flow)

Prices *establish direction of any power flow (low to high)*

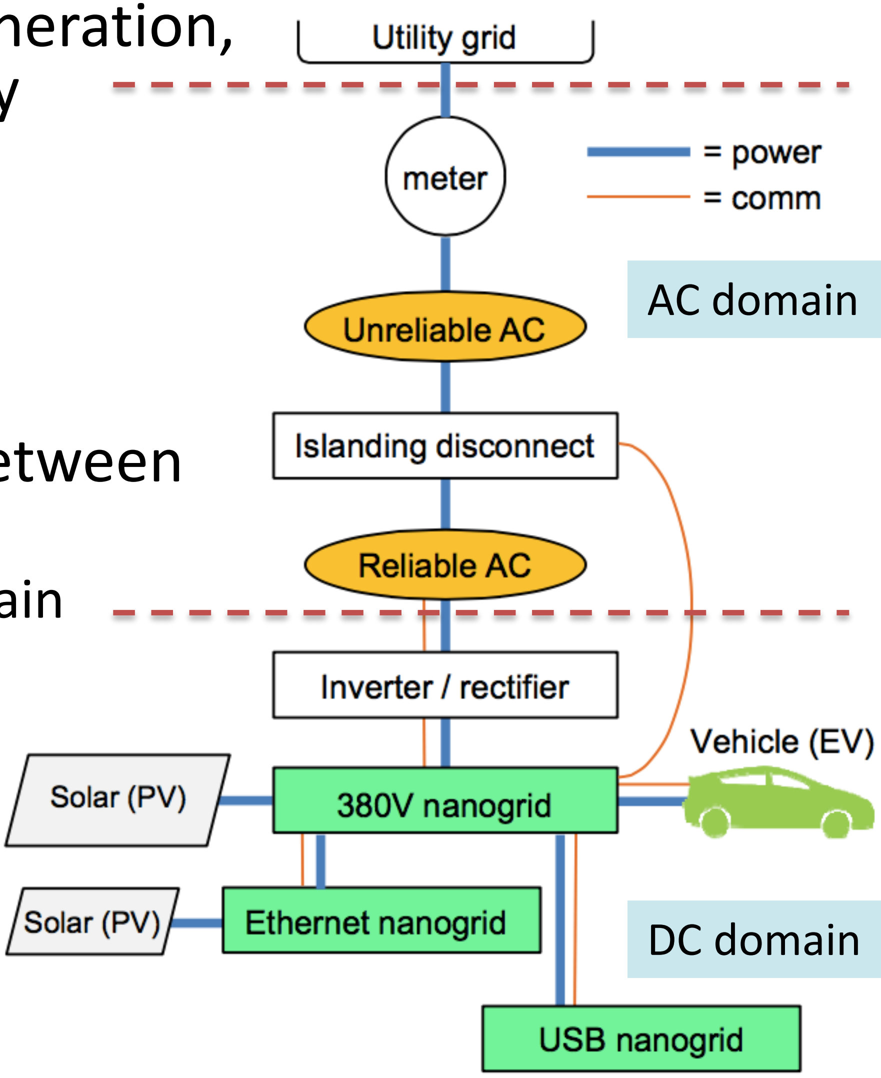
Power Allocation

- `Allocate`: Each GC announces to the other how much power is available
  - *The lower power level is set for the exchange quantity*
  - *Power flows across the link*



Proposed deployment path

- Use DC as integrator of local generation, local storage, vehicles, reliability
  - Storage integral to nG controller
  - Enables "Direct DC"
- Enable modest reliable AC
  - e.g. refrigerator
- Amount of power exchanged between DC, AC small
  - Most DC power stays in DC domain
- Can add DC capability incrementally and organically
- Can exchange power with neighboring buildings
  - Useful in disaster scenarios



Reliable Communications

Issue

- Communications (VOIP, Internet) no longer reliable during grid outages
- AC UPS are expensive, inefficient, non-optimized

Solution

- All communication devices be USB-powered
- Consumers have USB hub with integral battery
- Battery provides reliable power for many hours
- Hub can signal when on battery
  - Devices can reduce services to save power
- Could connect PV panel for multi-day reliability
  - Buy solar one panel at a time
  - No permits, no prof. labor – plug-and-play
- Can take camping

Summary

- Need network model of power
  - LPD is one – highly practical
- Nanogrids can be key to success of microgrids
  - Can be deployed faster, cheaper
- Essential technologies
  - Pricing
  - Bi-directional power
  - Higher capacity links
- Keep traditional grid, but make it *less* reliable

- Nanogrids are a “generally useful technology”

Thank you