Innovating Energy Access for Remote Areas: Discovering Untapped Resources

Optimizing Device Operation with a Local Electricity Price

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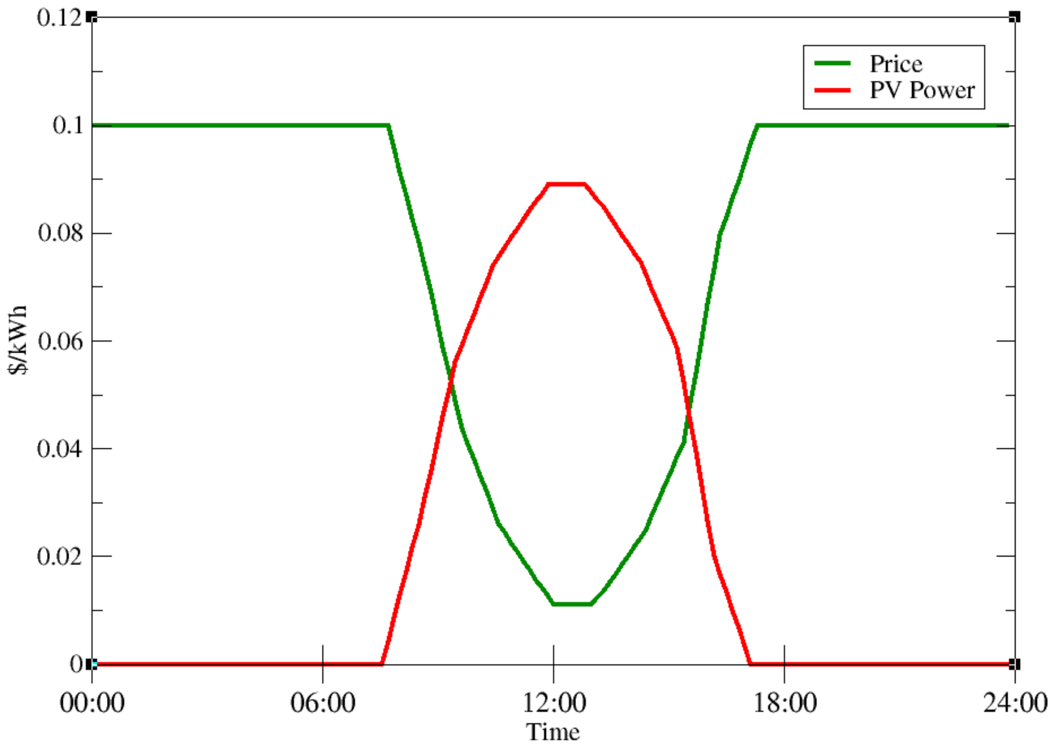
Introduction

- Always important to make best use of electricity resources - generation, storage
  - Especially in energy access context
- Need to balance supply/demand
- Hypothesis:
  - Price is essential to doing this
  - Prices should be local
  - Local price can be used to shape demand to better match it to supply

Creating a local price

- Context: stand-alone system of local photovoltaic (PV) power and a battery



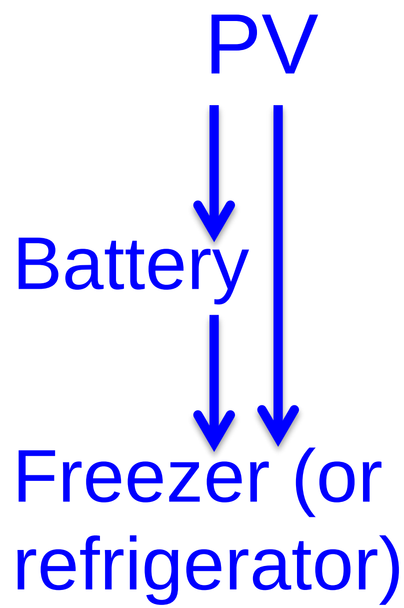
- The local price tracks power availability
  - lowest when PV output is highest

Purpose of project

- Explore/Apply the concept of "Local Power Distribution"
  - "Local Power Distribution with Nanogrids", Bruce Nordman and Ken Christensen – 2013 (first proposed May, 2010)
- Explore the behavior of a device that controlls itself with the current and forecast "local price" of electricity
- Quantify benefits
- Not try to create *best* system

How the simulator works

- System components
  - Freezer
  - Refrigerator
  - PV Source
  - Battery



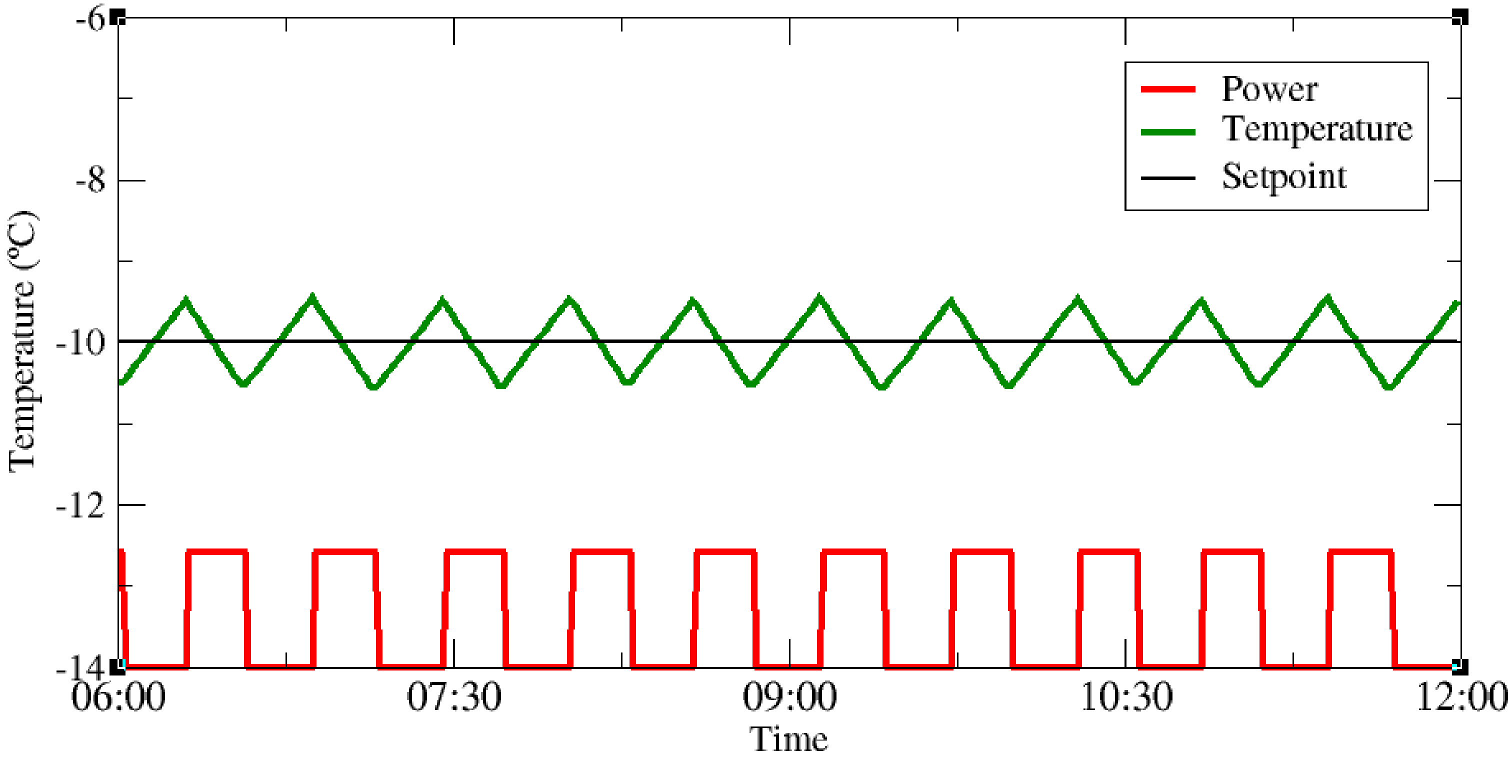
- 2 simulations
  - Constant price
  - Variable price

How the simulator works

PV output → Price/ Forecast → Device Setpoint → Device Behavior

- Process a series of steps
- Each step as simple as possible
- “Layered approach”
  - like Internet technology
- Complexity contained

Freezer — Constant price



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

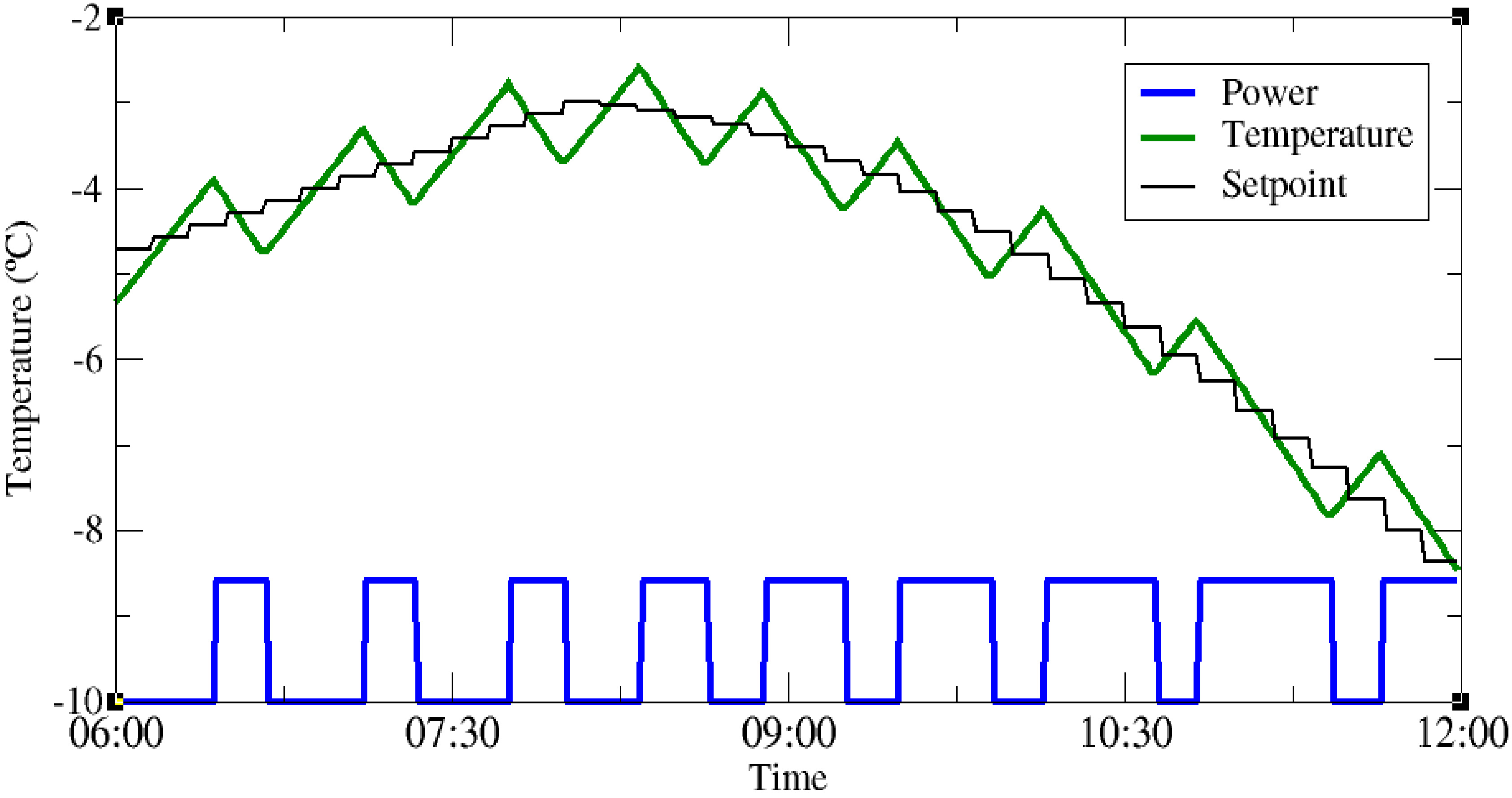
Device operation

- Price is current price plus forecast (24-hour)
- Price can change any time
- Forecast determines setpoint changes
- Device stays within 0.5 C of setpoint
    - Compressor **on**: until 0.5 C **below**
    - Compressor **off**: until 0.5 C **above**

- Freezer range: -3 C to -18 C (-10 C nominal)
- Refrigerator range: 1 C to 6 C (3 C nominal)

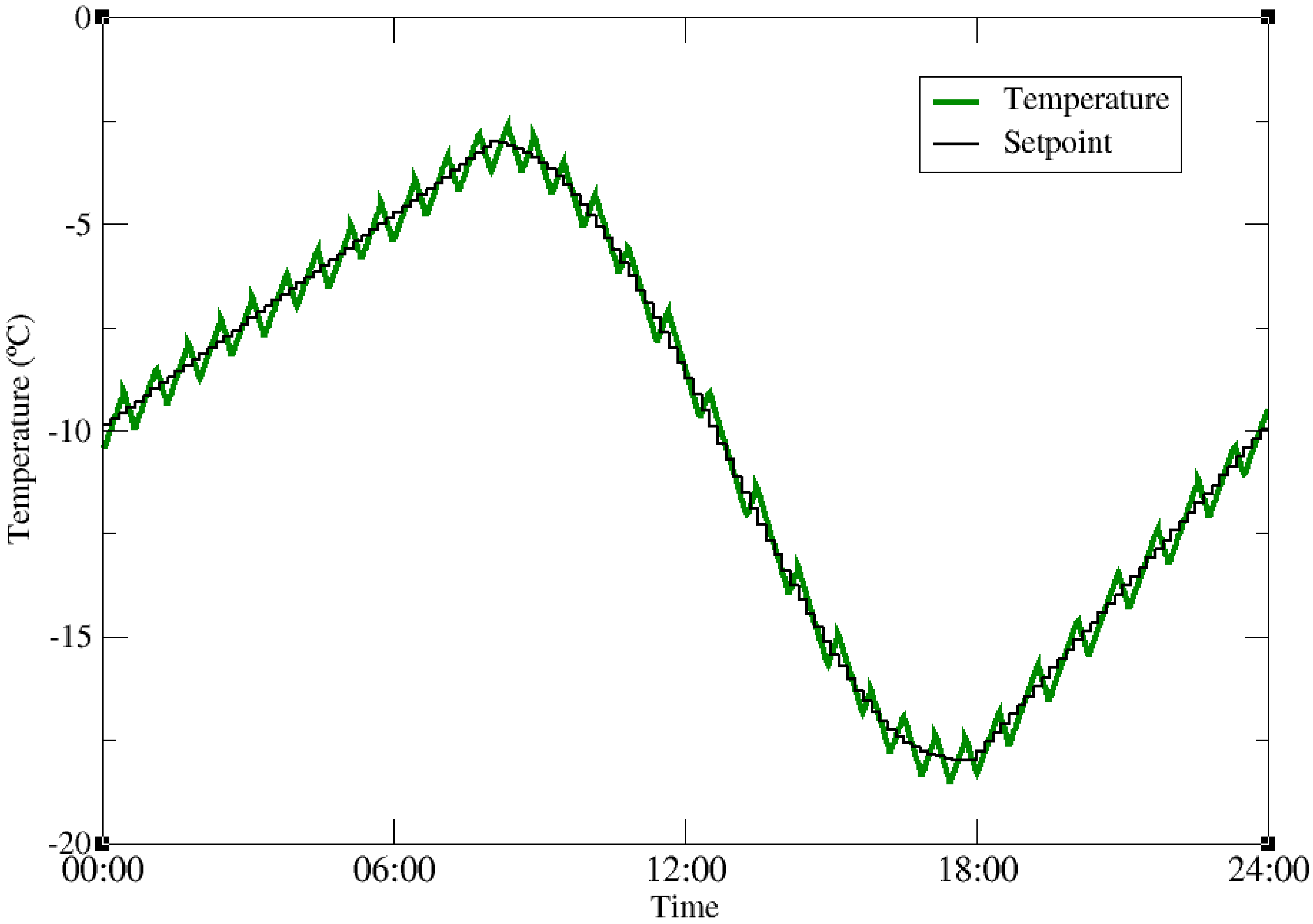
- Refrigerator like freezer except less interesting

Freezer — Variable price (6 hours)



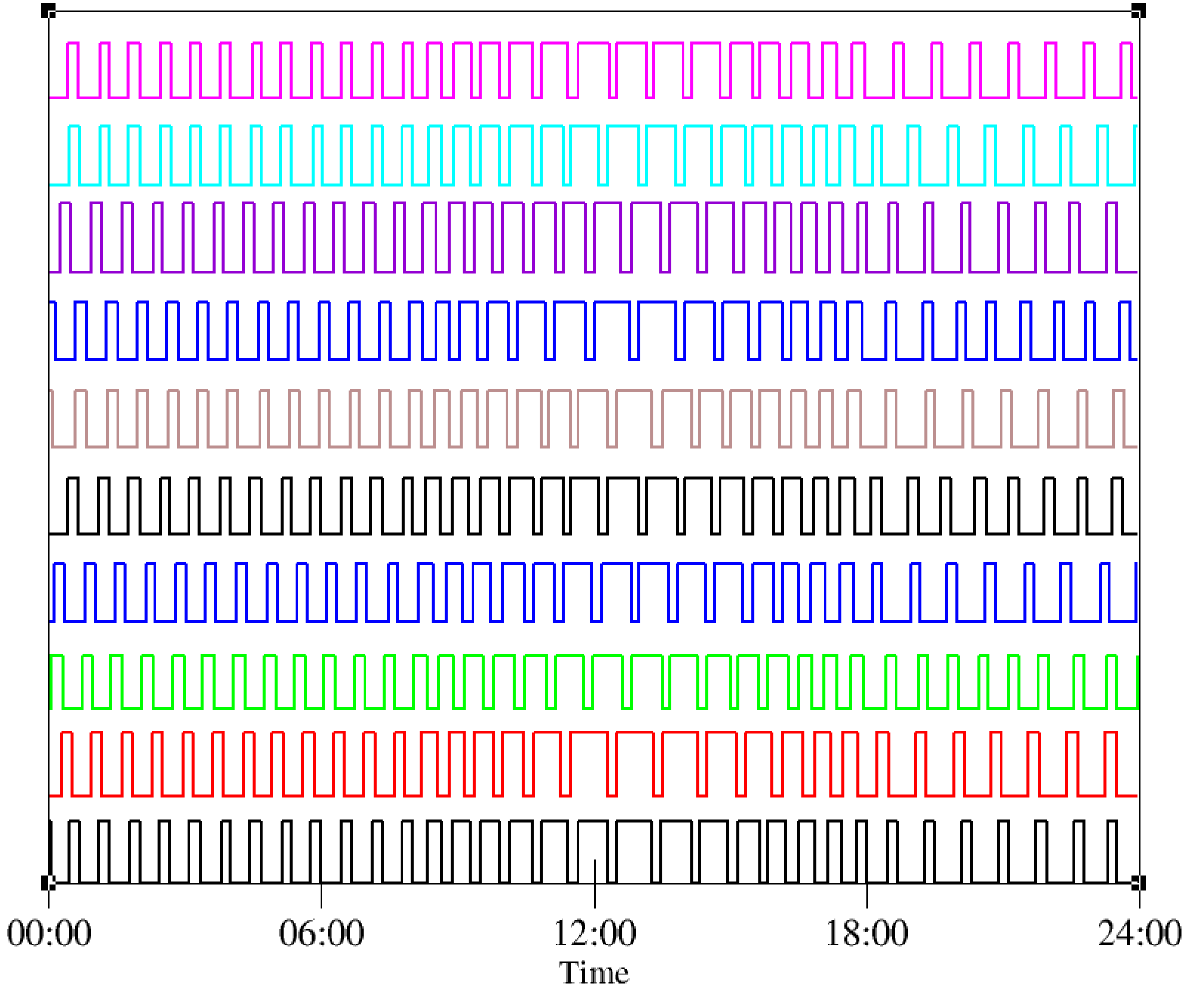
- Variable compressor on-times and off-times
  - (10 minute minimum on-times)

Freezer — Variable price (24 hours)



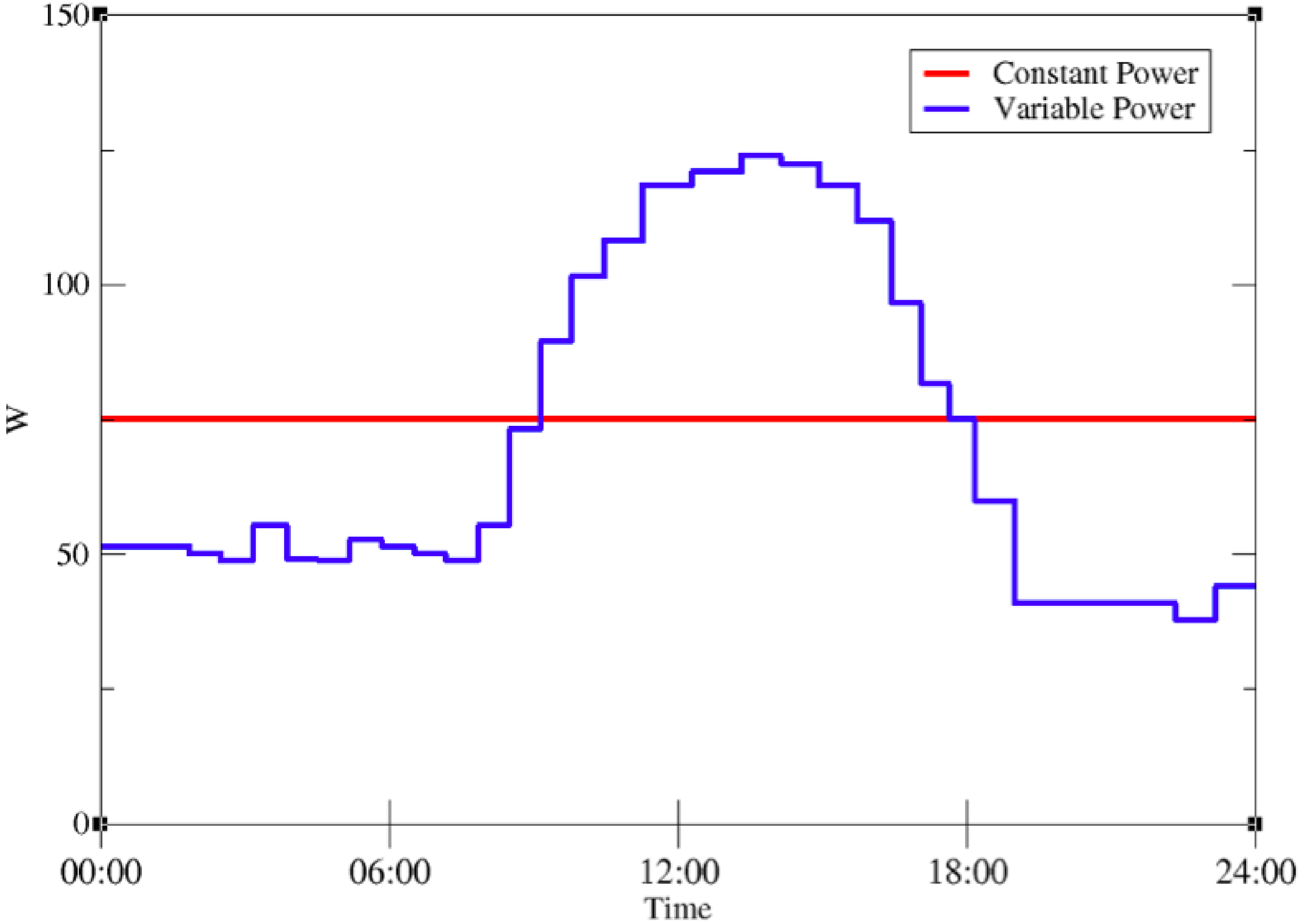
Multiple device results

- 10 Freezer (24 hours) - Power Consumption Distribution
  - key parameters randomized

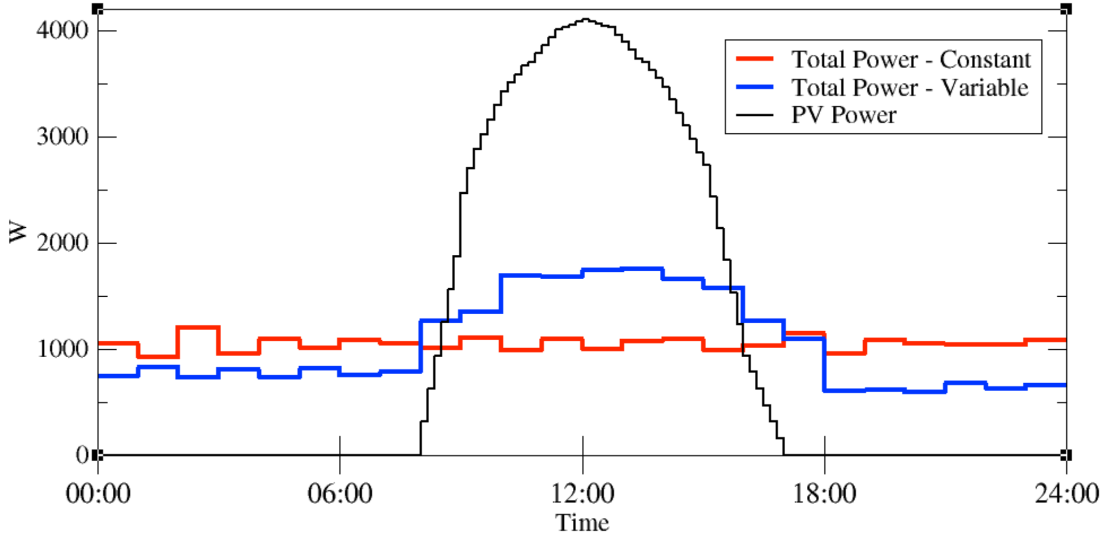


Freezer energy use

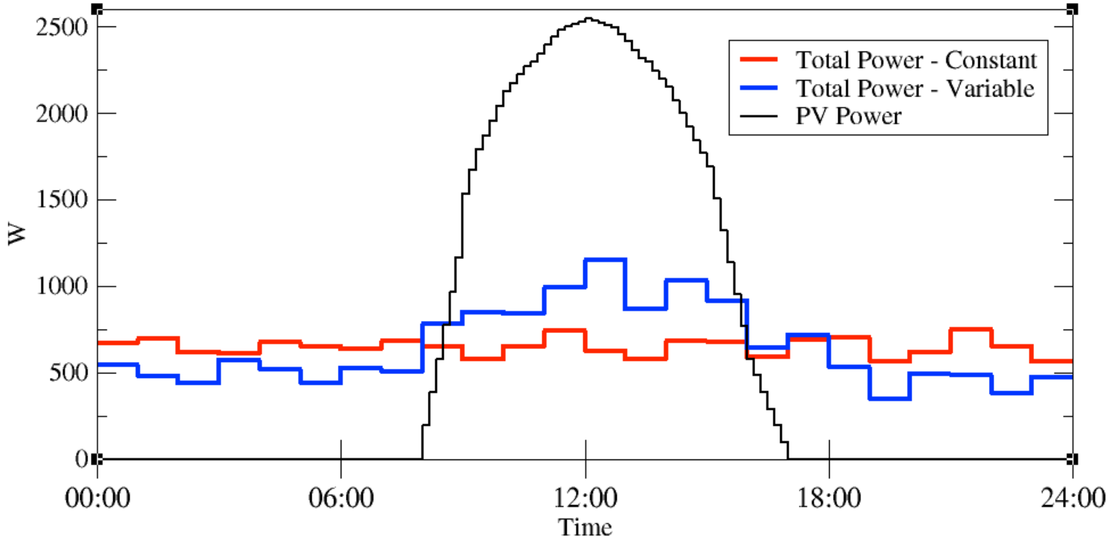
(average power per cycle)



Consumption vs. PV output



15 freezers



15 refrigerators

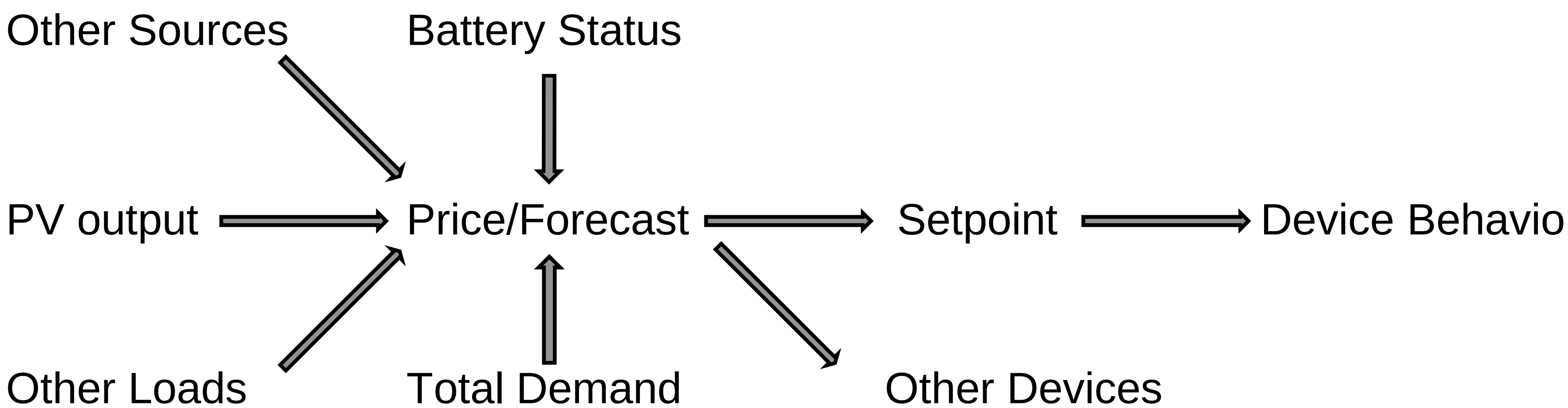
Results

(kWh/day – 15 units)

- More Direct PV; Less Battery; Less Loss

	Freezer		Refrigerator	
	Const.	Var.	Const.	Var.
Device energy	25.1		15.5	
Direct PV energy	8.6	12.8	5.4	7.5
Direct TV fraction of total	34%	51%	35%	48%
change constant to variable	49%		37%	
Battery energy	16.4	12.2	10.1	8.0
change constant to variable	4.2		2.1	
change constant to variable	-26%		-21%	
Battery loss (kWh)	1.64	1.22	1.0	-.8
change constant to variable	0.42		0.21	

More complex systems possible



- Simple
- Generic
- Works with networks of grids

What is a Nanogrid?

"A ~~small~~ electricity domain"
simple

- Like a microgrid, only smaller / less complex
- Has a single physical layer (voltage; usually DC)
- Is a single domain:
  - administration, reliability, quality, price, capacity
- Can interoperate with other (nano, micro) grids and local generation through gateways
- Wide range in technology, capability, capacity

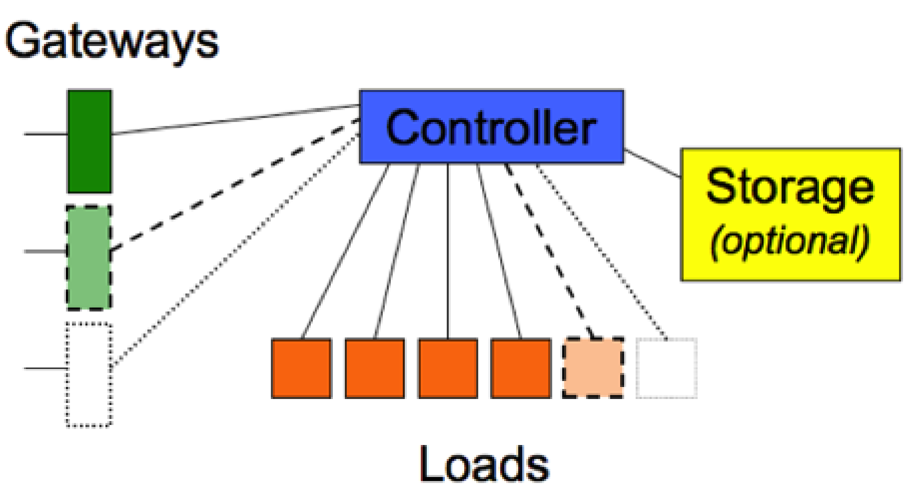


Image from Eric Brewer talk
"**Energy in the Developing World**"
January 14, 2010
(LoCal Retreat)

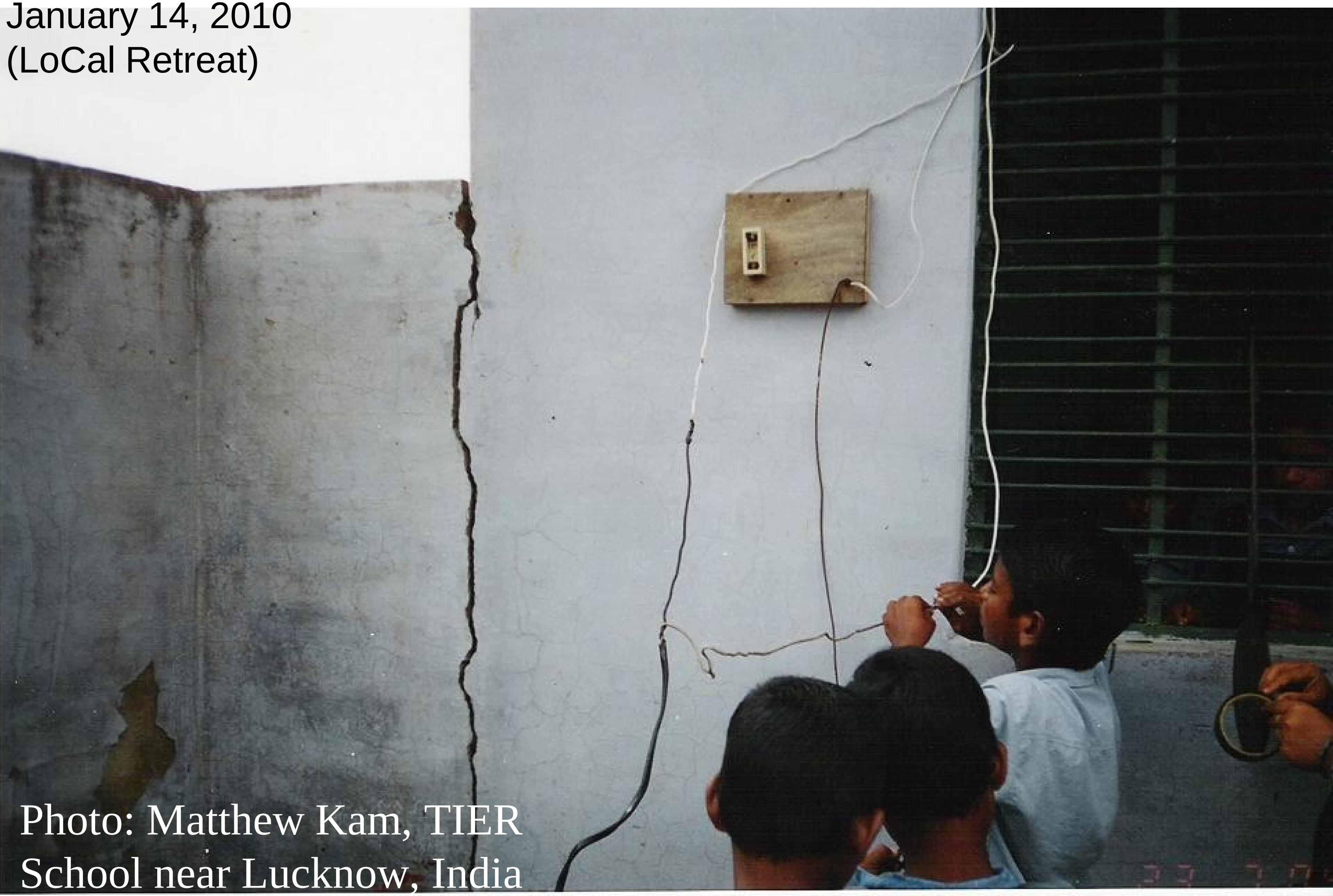
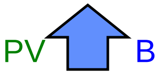


Photo: Matthew Kam, TIER
School near Lucknow, India

Village example

- Start with single house – car battery recharged every few days
  - Light, phone charger, TV, …
  - Add local generation – PV, wind, …



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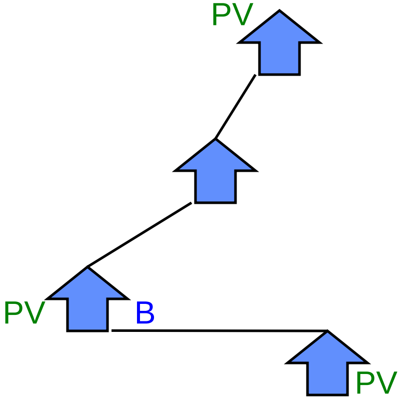
- Neighbors do same
  - Interconnect several houses



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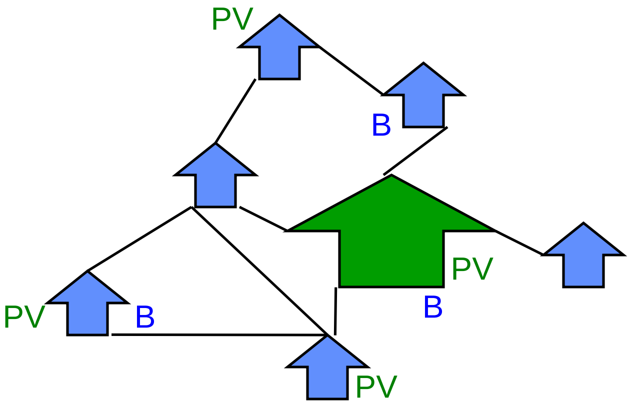
- School gets PV
  - More variable demand



- Eventually all houses, businesses connected in a mesh
  - Can consider when topology should be changed
- Existence of generation, storage, households, and connections all dynamic

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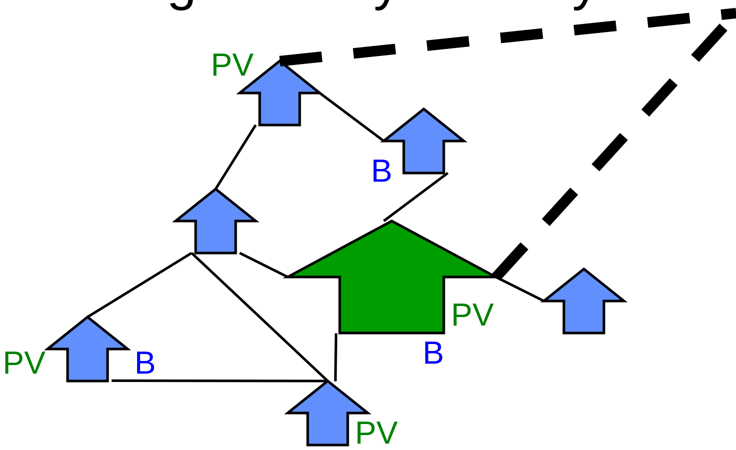
- Existence of generation, storage, households, and connections all dynamic
- Can later add grid connection(s)



From **no electricity** to **distributed power** – skip traditional grid;
Similar to **no phone** to **mobile phone** – skip landline system

Technology issues

Features / characteristics:

- Flexible
- Easy sharing
- Safe
- Optimal
- Inexpensive

Must be:

- Digitally managed; plug-and-play
- Networked
- Same everywhere

Thank you