



PROFESSIONAL TRAINING REPORT

*Sathyabama Institute of Science and
Technology (Deemed to be University)*

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

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REGISTER NUMBER : 39140063

VATIO®



Certificate OF INDUSTRY INTERNSHIP

This is to certify that

S.VIJAYA RAAGHAVAN

Studying **3rd Year, B.E, EEE** in **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY**

has successfully completed the Industry Internship Programme at VATIO Energy India Pvt Ltd, Chennai
through Online from 21st July to 05th August 2021 in the area of
"Solar Photovoltaic system & its Design Practices"

Best wishes from VATIO Energy for future endeavors !

G.Rajaganesan, Director - Technical
VATIO Energy India Pvt Ltd.

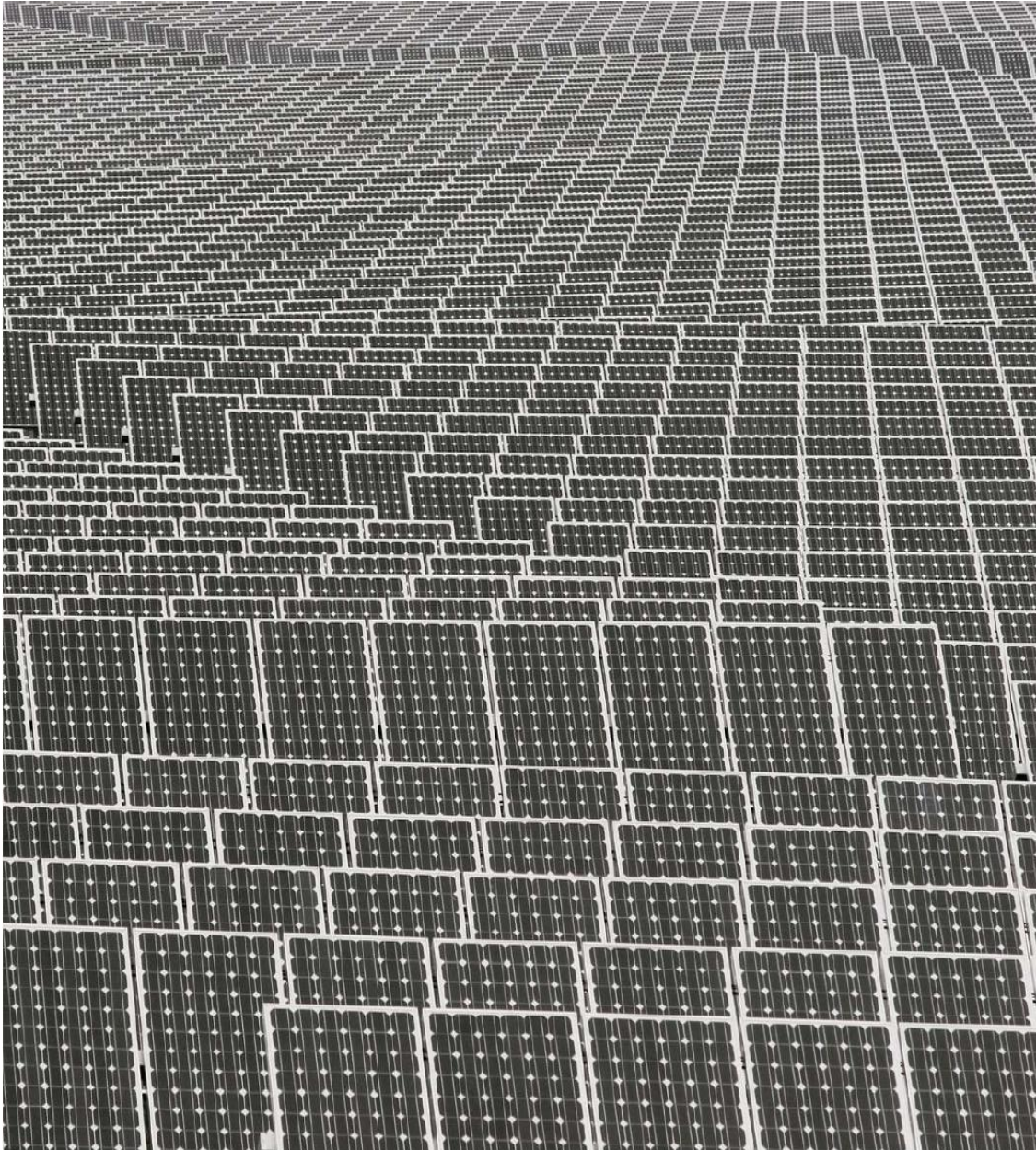


05th August 2021

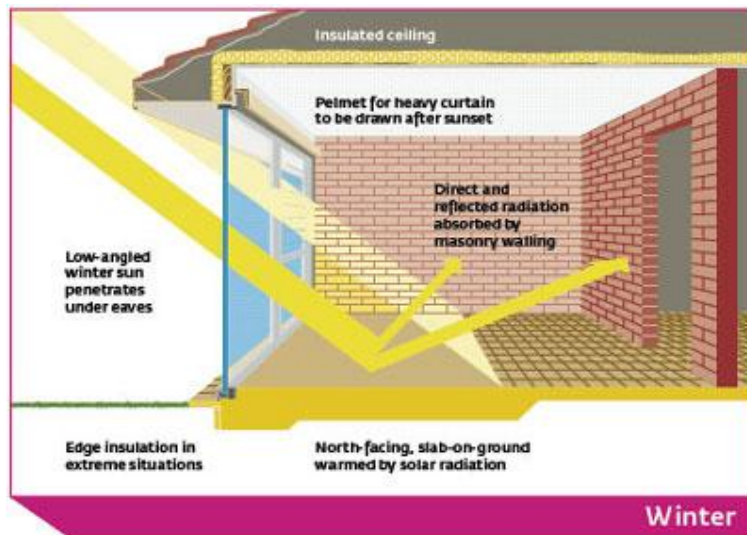
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Solar Photovoltaics

Making Electricity from Sunlight



Methods of Harvesting Sunlight



Passive: cheap, efficient design, block summer rays, allow winter



Solar Thermal: ~30% efficient; cost-competitive; requires direct sun; heats fluid in pipes that then boils water to drive steam turbine.



Solar hot water:

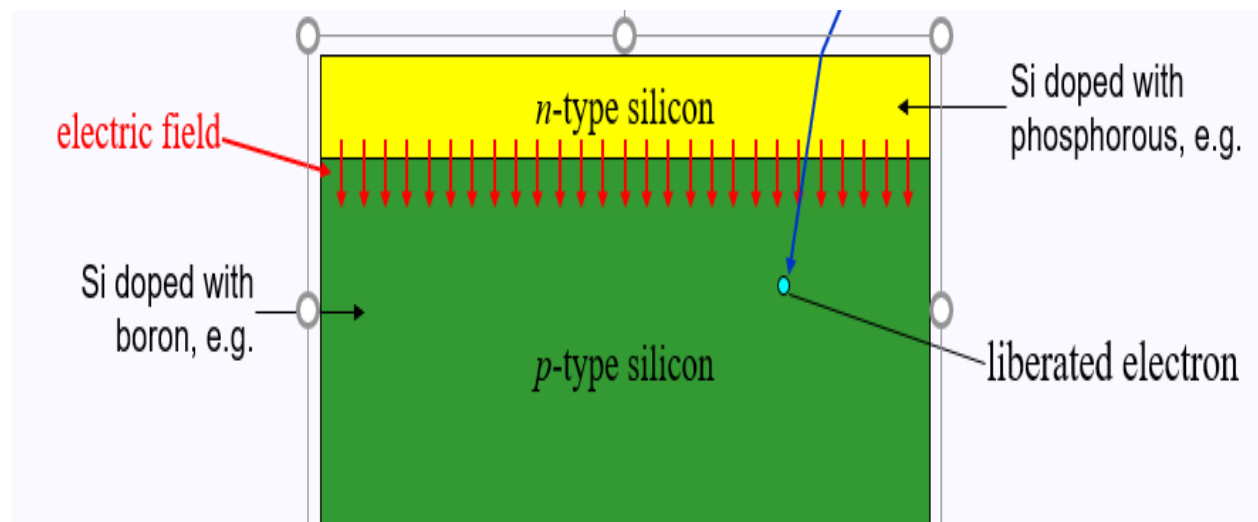
Up to 50% efficient; several \$k to install; usually keep conventional backup; freeze protection vital.

Photovoltaic (PV):

Direct electricity; 15% efficient. \$5 per Watt to install without rebates/incentives. Small fraction of roof covers demand of type.

Photovoltaic (PV) Scheme

- Highly purified silicon (Si) from sand, quartz, etc. is “doped” with intentional impurities at controlled concentrations to produce a p-n junction
 - p-n junctions are common and useful: diodes, CCDs, photodiodes, transistors
- A photon incident on the p-n junction liberates an electron
 - photon disappears, any excess energy goes into kinetic energy of electron (heat)
 - electron wanders around drunkenly, and might stumble into “depletion region” where electric field exists (electrons, being negative, move *against* field arrows)
 - electric field sweeps electron across the junction, constituting a current
 - more photons → more electrons → more current → more power

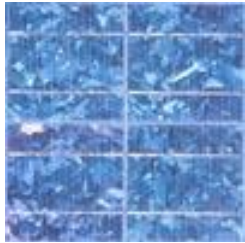


PV types

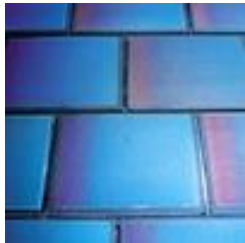
- Single-crystal silicon
 - 15–18% efficient, typically
 - expensive to make (grown as big crystal)



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- Poly-crystalline silicon
 - 12–16% efficient, slowly improving
 - cheaper to make (cast in ingots)



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- Amorphous silicon (non-crystalline)
 - 4–8% efficient
 - cheapest per Watt

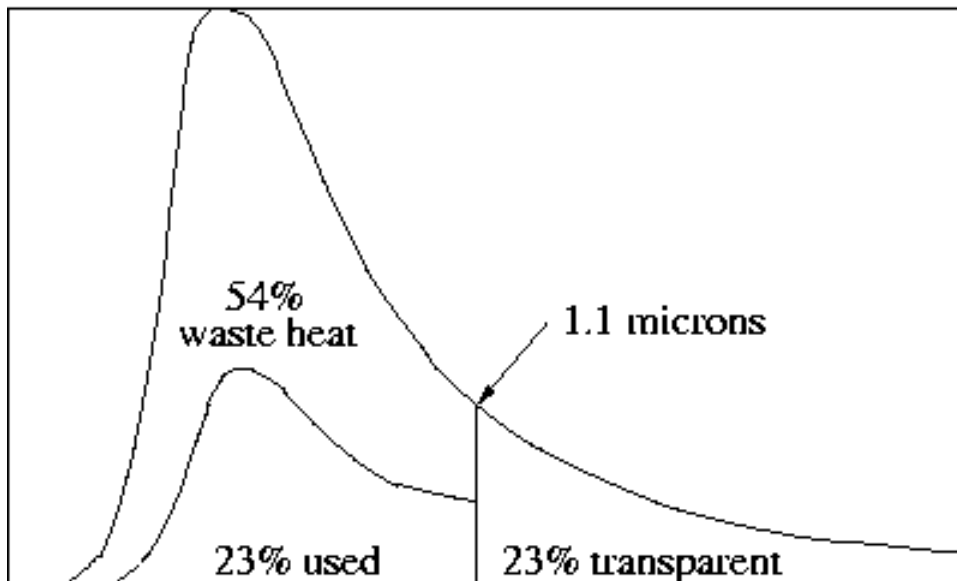


– called “thin film”, easily deposited on a wide range of surface types

How good can it get?

- Silicon is transparent at wavelengths longer than 1.1 microns (1100 nm)
 - 23% of sunlight passes right through with no effect
- Excess photon energy is wasted as heat
 - near-infrared light (1100 nm) typically delivers only 51% of its photon energy into electrical current energy
 - roughly half the electrons stumble off in the wrong direction
 - red light (700 nm) only delivers 33%
 - blue light (400 nm) only delivers 19%
- Altogether, the maximum efficiency for a silicon PV in sunlight is about 23%
 - defeating “recombination loss” puts the limit in the low 30’s%

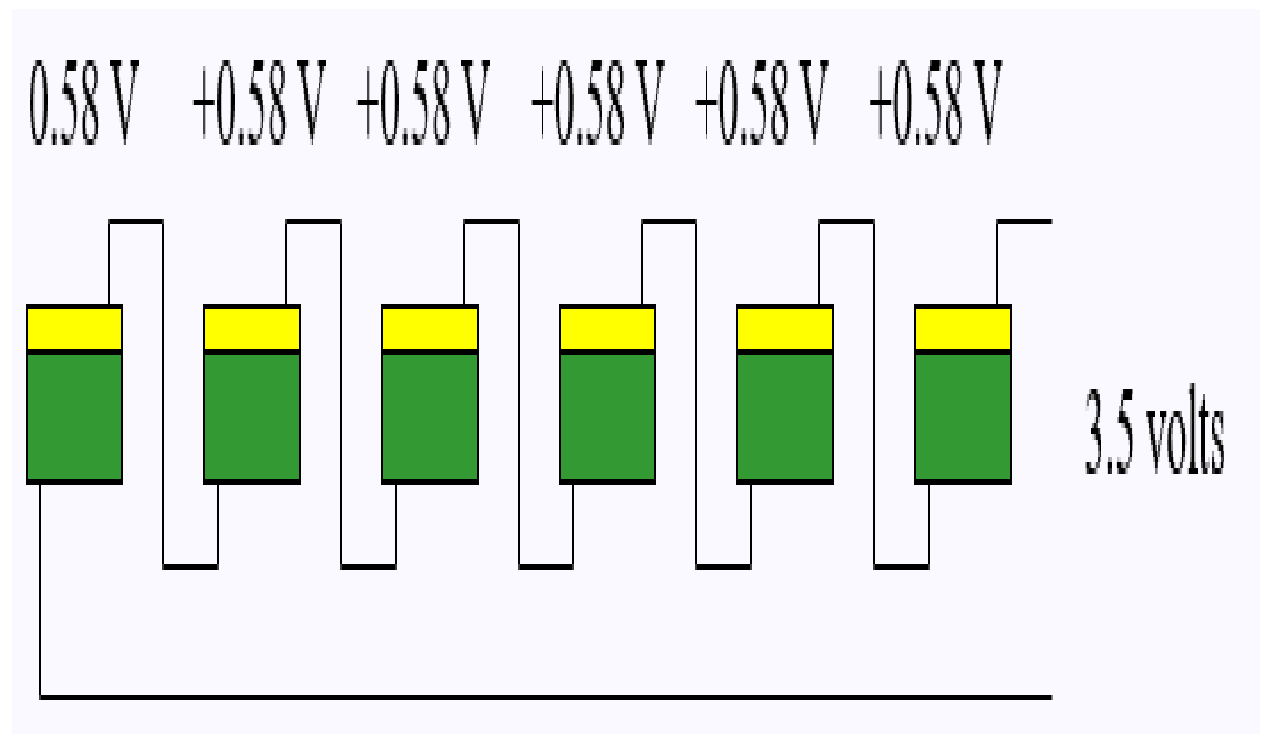
Silicon Photovoltaic Budget



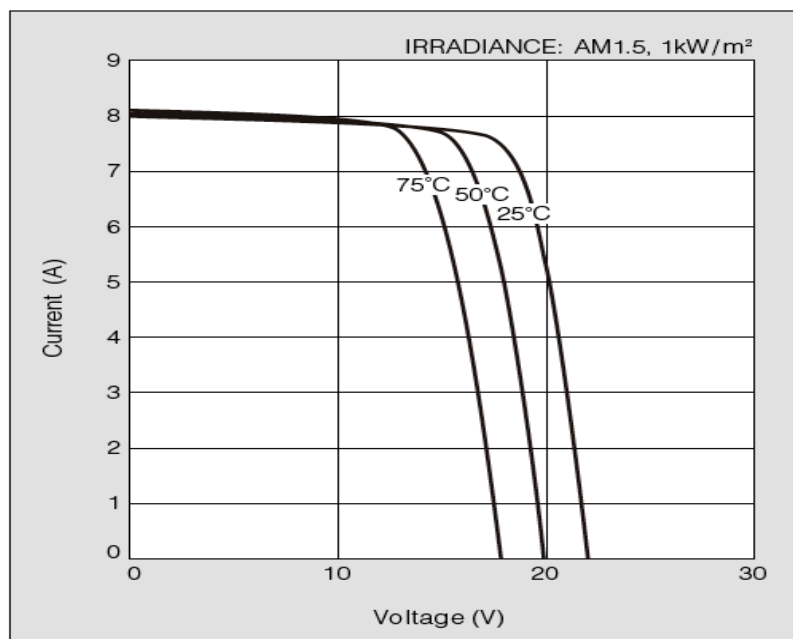
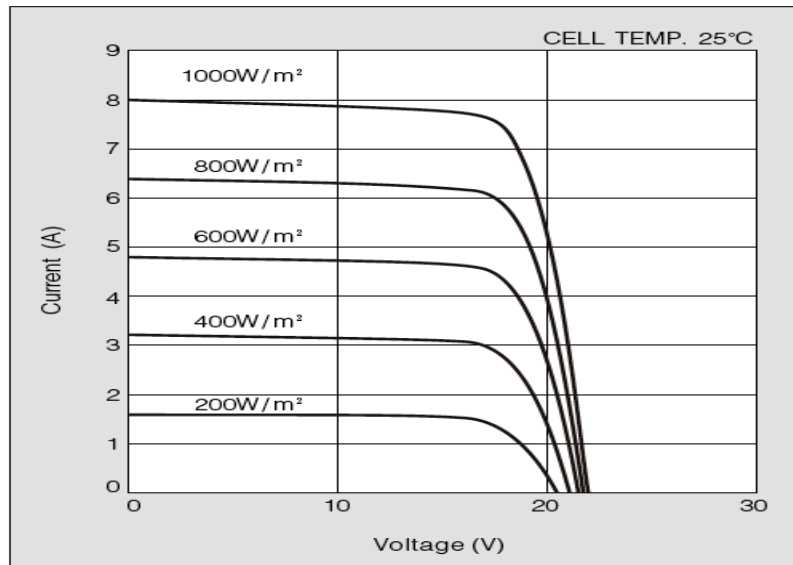
- Only 77% of solar spectrum is absorbed by silicon
- Of this, ~30% is used as electrical energy
- Net effect is 23% maximum efficiency

PV Cells as “Batteries”

- A single PV cell (junction) in the sun acts like a battery
 - characteristic voltage is 0.58 V
 - power delivered is current times voltage
 - current is determined by the rate of incoming solar photons
 - Stack cells in series to get usefully high voltages
 - voltage $\neq$ power, but higher voltage means you can deliver power with less current, meaning smaller wiring, greater transmission efficiency
 - A typical panel has 36 cells for about 21 V open circuit (no current delivered)
 - but drops to ~ 16 V at max power
- well suited to charging a nominal 12 V battery



Typical I-V curves



- Typical single panel (this one: 130 W at peak power)
- Power is current times voltage, so area of rectangle
 - max power is 7.6 amps times 17.5 V = 133 W
- Less efficient at higher temperatures

Solar Economics

- Current electricity cost in CA is about \$0.13 per kWh
- **PV model:** assume 5 hours peak-sun equivalent per day
 - in one year, get 1800 hours full-sun equivalent
 - installed cost is \$5 per peak Watt capability, no rebates
 - one Watt installed delivers 1.8 kWh in a year
 - panel lasts at least 25 years, so 45 kWh for each Watt of capacity
 - paid \$5.00 for 45 kWh, so \$0.11/kWh
 - rebates can pull price to < \$0.08/kWh
- Assuming energy rates increase at a few % per year, payback is < 10 years
 - thereafter: “free” electricity
 - but sinking \$\$ up front means loss of investment capability
 - net effect: cost *today* is what matters to most people
- Solar PV is on the verge of “breakout,” but demand may keep prices stable throughout the breakout process.

Solar’s Dirty Secret

- It may come as a surprise, but the sun is not always up
- A consumer base that expects energy availability always is not fully compatible with direct solar power
- Therefore, large-scale solar implementation *must* confront energy storage techniques to be useful
 - at small scale, can easily feed into grid, and other power plants take up slack by varying their output
- Methods of storage (all present challenges):
 - conventional batteries (lead-acid; cheapest option)
 - exotic batteries (need development)
 - hydrogen fuel (could power fleet of cars, but inefficient)
 - global electricity grid (always sunny somewhere)
 - pumped water storage (not much capacity)

A Modest, Stand-Alone System



- In 2007, I set up a small PV system to power my living room
- Used two different panel types, explored several charge controllers and configurations
- Built mounts to allow seasonal tilt adjustments
- Larger panel is 130 W poly-crystalline silicon at 16% efficiency
- Smaller is 64 W thin-film triple-junction at 8% efficiency
- Large panel handled TV, DVD/VCR (system A), smaller one powered light (system B)

Dual System Components (covers removed)

MPPT charge controller, system A

breaker box and shunts for current measurement

system monitor

400 W inverters for systems A & B

charge controller, system B

extension cords go inside to appliances

unused MPPT charge controller

ground wire (to pipe)

class-T fuse (110 A)

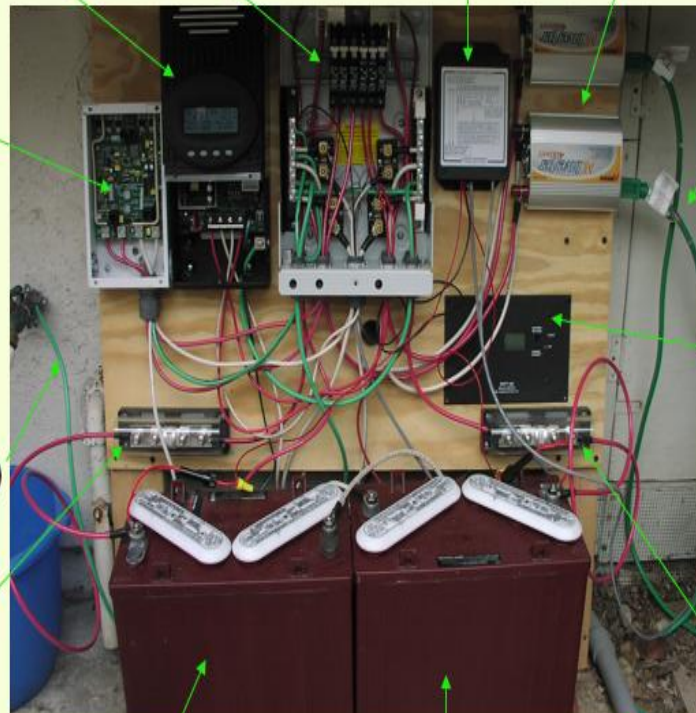
class-T fuse (110 A)

green: ground
red: positive
white: neutral

12 V lead-acid golf-cart battery for system A: holds

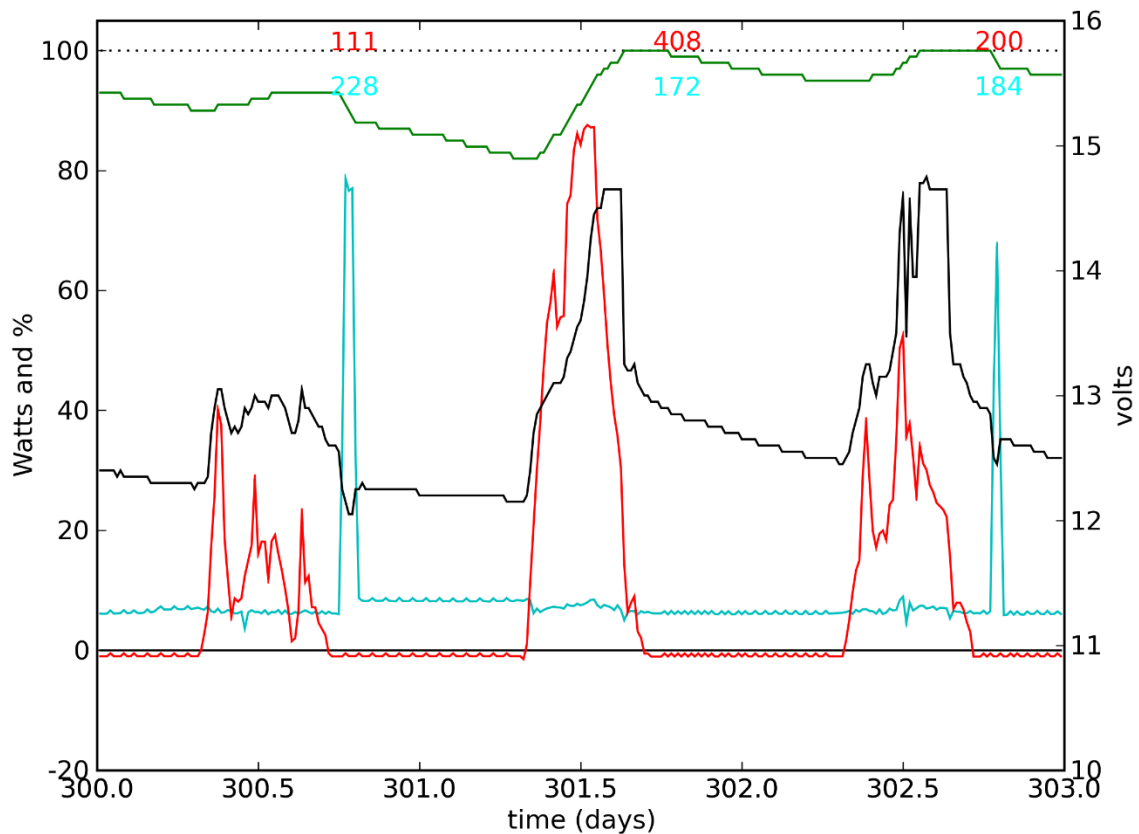
identical 12 V battery for system B

conduit carrying PV input wires



Three days of PV-TV monitoring

Home PV monitor for three late-October days in 2007: first very cloudy, second sunny; third cloudy



green: battery % full.

black: battery voltage (right hand scale).

red: solar input, Watts.

cyan: load usage; baseline for inverter, intermittent TV use numbers at top are total solar yield (red) and total system usage (cyan) for that day, in Watt-hours

System Upgrades

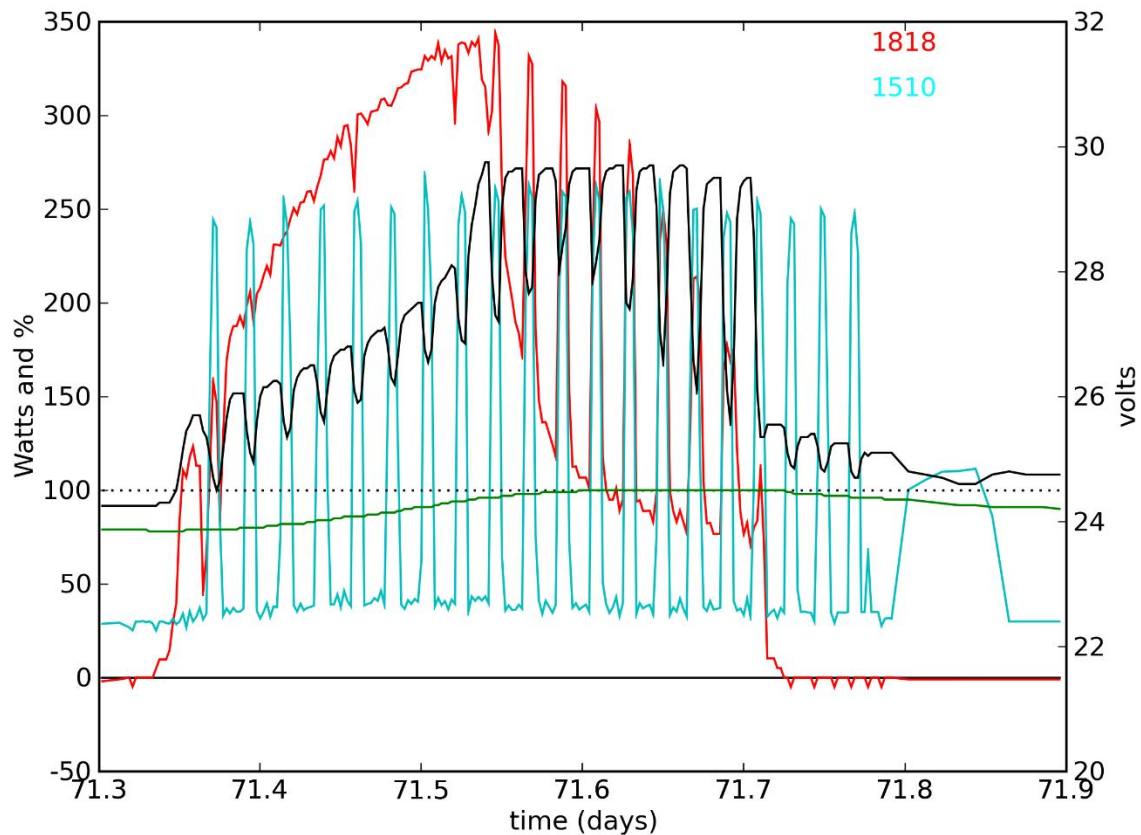


extensions on mounts allow tilts to 50°

portion shown here only gets 10° and 20°

- Over time, system has grown
 - but into single system
- Four 130 W panels shown at left
- Beefy inverter (3.5 kW max)
- “Smart” control to switch to grid power input when batteries low
- Started running refrigerator most of the time off these four panels
- Expanded to 6 panels
- Now 8 panels after we moved
 - handles 60% of electricity

Refrigerator Cycles

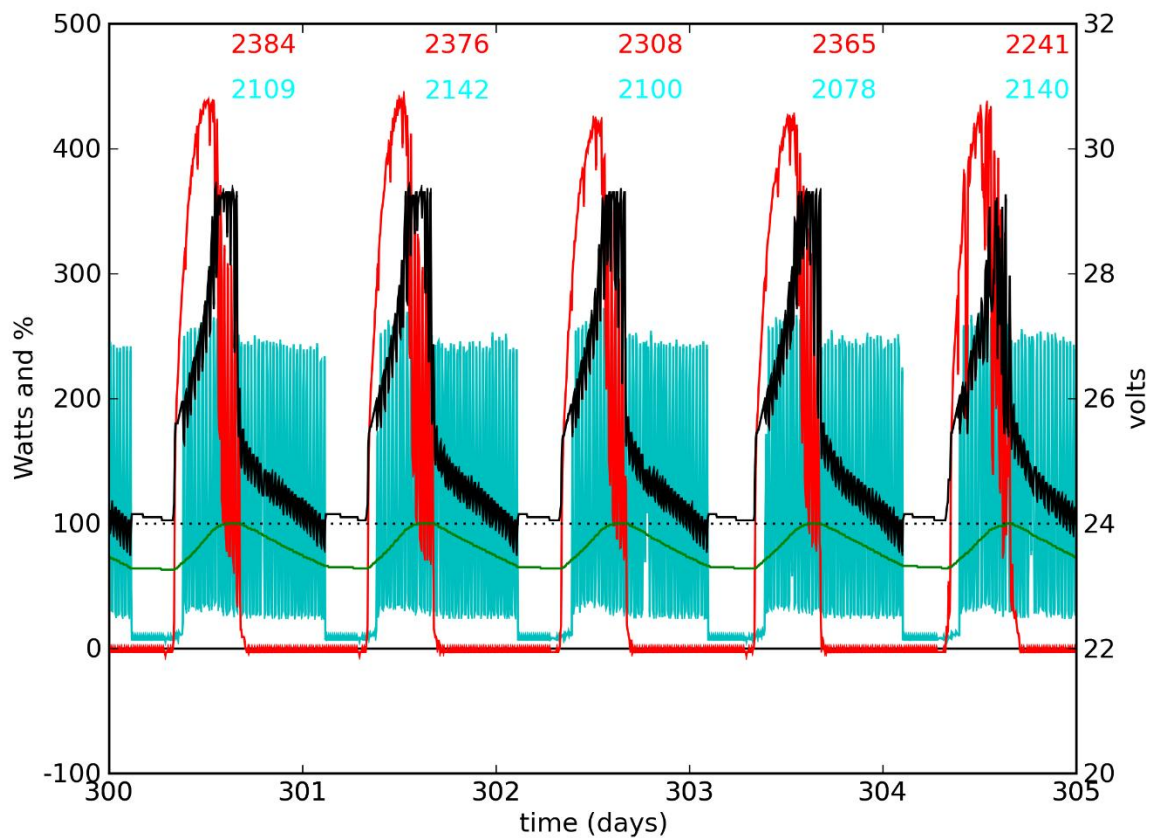


In this period, got 1818 W-h from sun, used 1510 W-h

Getting 1818 W-h from 340-W capacity → 5.3 hours equiv. full sun

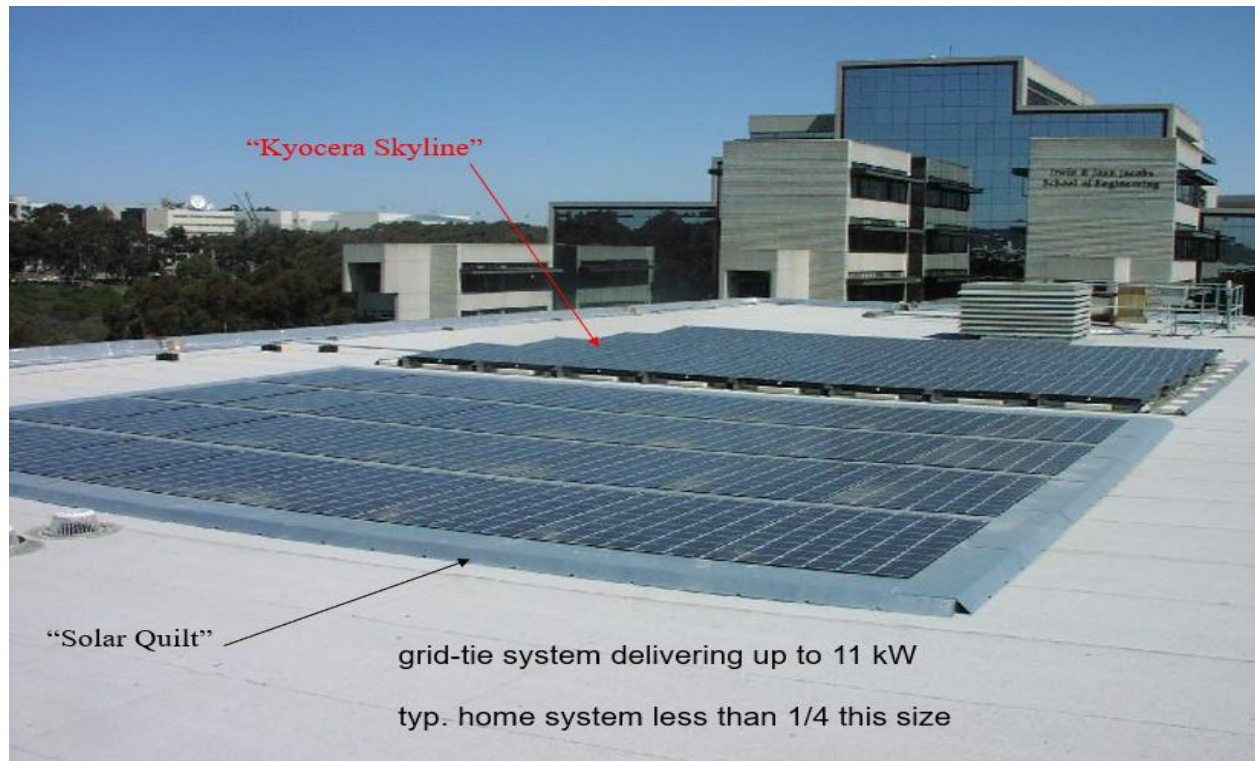
1. With three panels, I could tackle something more worthy, like the refrigerator.
2. Can see cyclic behavior as fridge turns on and off
3. Once battery reaches absorb stage voltage (~29.5 V), can relax current to battery (falling red envelope)
4. When fridge pops on, need full juice again
5. Some TV later in day

Smart Inverter Scheme



1. Smart inverter can shut off when battery gets low, using grid power to supply to loads.
2. Inverter comes back on when battery voltage hits a certain level.
3. Note consistency of energy supplied (red numbers) and energy used (cyan numbers).
4. Infer $2107/2358 = 89\%$ efficiency across first four days (efficiency of sending solar juice to inverter, including battery).

The Powell Solar Array at UCSD



Powell PV Project Display



