Basics of Solar Electricity (& Storage)

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Agenda



- Solar Photovoltaic (PV) Introduction
- System Components
- Solar Path
- Sizing a PV System
- Optimizing a PV System
- Financial Considerations
- Energy Storage
- Case Study Westbrook House

Solar Photovoltaic PV

- Panels (or modules) that produce electricity from sunlight are called solar photovoltaic (PV) panels
- Photons knock electrons out of an atom and they travel through a circuit to restore balance





System Components



Various alternative materials are under development.

Solar PV Panel



Cells (60 in this module)

Full assembled piece called solar panel or solar module

And before you ask . . . They are tested for hail resistance with two impact tests that UL conducts: 1. Drop a two-inch solid steel sphere from a height of 51 inches onto the surface of the PV module, the energy equivalent of a hail stone measured at one inch and three-eighths in diameter falling at terminal velocity through the sky. 2. Shoot a spherical chunk of ice (1" dia) from a pneumatic cannon at 10 to 13 critical locations on the PV module at about 52 miles per hour.

PV (DC) to Grid (AC)



- Direct current (DC)
 - PV panels produce DC
 - Batteries also use DC
- Alternating current (AC)



- Most transmission and use is AC
- Inverters are devices that convert DC to AC and synchronize with the power grid (at 60Hz in the US)

Panel Efficiency



- Articles often appear touting breakthroughs in panel efficiency
- Negative articles will claim solar panels are "only 18% efficient"
- Does it matter?
 - Yes and No

Panel Efficiency



- Higher panel efficiency reduces the number of panels you need for a kWh output goal
 - Also reduces other component counts and space needed
- But lower efficiency panels might be much less expensive
 - Is it enough savings to offset the space and component differences?
- Look at the overall \$/kW of the installation to decide

Solar Inverters







String inverter One per ~22 panels

No electronics on roof Easier to connect batteries Lower cost per Watt

Doesn't optimize each panel Wires run in DC Single point of failure

String inverter + DC optimizers

Optimizes each panel output Panel level monitoring

Wires run in DC Added cost

Microinverter

Enphase

one per panel

Optimizes each panel output Wiring run in AC Panel level monitoring

Need another inverter to integrate batteries

Power and Energy



- Panels and Inverters will be rated by their
 POWER in Watts or kW
 - -kW = kilowatt (1,000 Watts)
- How much ENERGY something uses or produces will be stated in kWh
 - kWh = kilowatt-hour (1,000 Watts used during an hour)
 - Your electric company bills you for kWh

If your TV draws 150W of power and you watch it for 10 hours, you'll use: 150W * 1kW/1,000W * 10 hrs = 1.5kWh

Solar Mounting





Ballast mounted

Ground mounted



Grid Tied or Battery?



- Most homes are grid tied connected to the electrical grid
 - Power flows back and forth to/from the grid
 - Solar shuts down when the electric grid is down



- Very few homes run with batteries only
- Some homes have batteries to supplement the solar and grid-tie



Microinverter Grid Tied System with Microinverters





Wiring is all AC – more familiar to electricians

Net Metering





Solar Panel Cost Drop





Source: Bloomberg, New Energy Finance & pv.energytrend.com

Solar System Costs 2020





- PV Panels
- OH/Profit
- Rack/Wire
- Labor
- Sales/Market
- Inverters
- Permit/Tax

Solar Path

Note: The following information has a northern hemisphere bias



Sun Path





Winter solstice sun path in Dallas, TX at 33°N latitude sun rises 28° South of East (118°az - 90°E = 28°) max altitude = 33°

Summer solstice sun path in Dallas, TX at 33°N latitude sun rises 28° North of East (90°E - 62°az = 28°) max altitude = 81°



Sun Path Projection – 33°



Annual sun path in Dallas, TX at 33°N latitude



Sizing the System

Efficiency First



- Make sure your home/business has addressed energy efficiency
- An efficient home/business will need a smaller solar system to meet the needs
- Many efficiency projects have a faster payback than a solar PV system
- One strategy is to add a small solar system now, then continue to work on efficiency to bring down your use

Rules Next



- Grid Tied: Your utility needs to have an interconnect agreement available
- Net Metering: What are the net metering rules for your electric supplier?
 - Some utilities will pay or credit you for excess energy sent back, but sometimes at a different rate
 - Others will take your excess energy with no compensation

System Sizing



 Review past utility bills – understand the usage



System Sizing



- Most systems are sized to produce some % of the load, or match the lowest monthly load (strategy if your utility does not buy or credit excess monthly production)
- Sometimes the size is limited by the available sunny area on the roof
- You can estimate system production using the free PVWatts tool (<u>https://pvwatts.nrel.gov/</u>)

PVWatts for 5kW System **RESULTS** 7,646 kWh/Year*



Print Results

System output may range from 7,455 to 7,829 kWh per year near this location. Click HERE for more information.

Month	Solar Radiation (kWh/m ² /day)	AC Energy (kWh)	Value (\$)
January	4.69	589	59
February	4.89	541	54
March	5.29	640	64
April	5.78	663	66
May	5.68	656	66
June	6.34	691	69
July	6.52	716	72
August	6.54	731	73
September	6.00	653	65
October	5.55	633	63
November	5.02	599	60
December	4.30	532	53
Annual	5.55	7,644	\$ 764

DFW area 5kW 180 deg AZ 33 deg tilt \$0.10/kWh

System Sizing



Overlay solar production with energy use



Optimizing the System

"Don't optimize the parts and pessimize the system" – Amory Lovins

Follow the Sun

For maximum production panels should face south with a tilt angle close to the local latitude.

June 21 Sun's Path Have minimal In the Sky shading on the panels. East North Photovoltaic Each kW of modules December **PV** panel produces ~1,400 kWh/yr Solar windows in DFW South West



Optimizing Solar



- For the most overall energy output:
 - Face panels as close to south as possible
 - Angle panels at about your latitude
 - You can gain a few more % if you can tilt the rack angle up / down seasonally
 - East-west tracking can increase output, but adds complexity
- If you are chasing peak energy reduction
 - You might aim your panels more toward the west to boost late afternoon output

My System Sizing Tips



- Get your total kWh use for a year and divide by your local kWh/kW solar figure (from PVWatts). For DFW this is about 1,500 (tilt of 30 degrees, aimed due south).
 - Example: 15,000kWh/year / 1,500 kWh/kW = 10.0 kW
 - This is your max size system, and should only be used if you have good net metering.
- Next, divide your lowest monthly usage by 115.
 - Example: 700kWh / 115 = 6.1 kW
 - This should be the minimum sized system. Stick close to this size if you don't have a decent net metering policy.
- That gives you a system range. Shooting for about 70-80% of max usually optimizes the cost and usefulness. Vendors will want to sell you as much system as they can, of course.

Financial Info

"Happiness does not require an expanding economy" - John Kenneth Galbraith, Economist

System Cost

Example for a 5.0 KW system (~16-20 PV panels):Total Installed Cost (\$2.90/Watt)\$14,500Utility Incentives (*if available, varies*)-Federal Tax Credit (30%)- \$4,350Final Net Cost (\$2.03/Watt)\$10,150

Equivalent Cost/kWh

\$0.057/kWh

25 year fixed cost of electricity from solar

Deregulated areas in Texas solar retail net meter plans: https://www.texaspowerguide.com/solar-buyback-plans-texas/

Federal Solar Tax Credit



- The Inflation Reduction Act of 2022 raised the solar tax credit back to 30% and extended it for a decade
- This is also applicable to storage batteries when coupled to a solar array
- Local credits/incentives/rebates can be found at the Database of State Incentives for Renewables & Efficiency https://www.dsireusa.org/

Buy, Finance, Lease, other?



- Typical options
 - Purchase installed system
 - Take out a loan to purchase
 - Solar panel system long term leasing options
 - Power Purchase Agreement long term agreement to buy kWh
- The most important things to know:
 - How much electricity do you use on an annual / monthly basis
 - The net \$/Watt solar installed
 - The kWh production of the system (your equivalent \$/kWh)
 - Then the purchase, borrow, or lease decision is a personal decision
- Remember, financing and leasing companies are like any other company, they offer these product options to make money

What's the Payback?

- What's the payback of any of the following?
 - Crown moulding
 - Fancy clothes
 - Solar PV
 - A big SUV
 - Stainless steel, high end appliances
 - Buying fancy coffee at a shop

\$10K

- Why do we only question the payback of solar PV (which actually has a payback) and ignore payback for almost everything else in our lives?
- The Internal Rate of Return (IRR) of a PV system is usually at least 8%. Where else can you get a guaranteed 25 year return of 8%?









Storage (Batteries)

Energy Storage Systems

Battery Storage



- Energy storage, usually from batteries, can be coupled with solar energy
- This allows the solar to operate during a power outage and recharge the batteries that are powering you during an outage (island mode)
- Depending on your house efficiency and battery size, you might be able to only power some basics with storage, or you could power the entire house
- Older battery storage used a lead acid battery array, but most new residential batteries are some variation of lithium-ion.

Battery Sizing



- The size will vary based on what all you want to run using the batteries. There are two key ratings:
 - Max kW this will tell you the maximum power draw. If your heat pump draws 3kW and your battery is rated for 5kW max, then it might work – however the startup surge that the heat pump draws might be to much for the battery.
 - kWh this will tell you how long the battery will last, and that time will vary based on how much energy you are using.

Case Study

Westbrook House

There is a great need for the introduction of new values in our society, where bigger is not necessarily better, where slower can be faster, and where less can be more. – Gaylord Nelson

Westbrook House



Compact, two story stacked



Westbrook House - www.enerjazz.com/house

Westbrook House



- Designed our passive/active solar house in 1996
- Won national award for innovative design
- A few features
 - Passive solar design
 - Structural insulated panels (SIP) for the shell
 - Solar water heating
 - Ground source heat pump for heating and cooling
 - Desiccant when air to air heat exchanger for fresh air
 - Clerestory windows for natural ventilation
 - Solar PV (photovoltaic) system
 - 3,200 gallons (12,000 liters) rain water collection/storage
 - Efficient appliances
 - Real time energy monitoring

Results

- 80% more energy and water efficient than typical home

Westbrook Load (no solar)





Added Solar PV in 2012



Our utility did not credit me or purchase any monthly excess production

- Looked at past utility use and sized the system to meet the lowest months usage
 - A few months were <400 kWh (Oct, Nov)
 - Average 440 kWh as a target (Oct, Nov, Apr)
 - Using PV Watts I selected a 3.7kW system: (14)
 240W panels and (2) 170W panels)
 - This would closely match our loads in the low use months and cover about 75% of our annual energy use

My Solar System Cost in 2012

- Total Cost: \$7,496

 Cost/Watt (3.7kW): \$2.03 (I did the installation)
- Tax Credit (30%): \$2,249
- Net Cost: \$5,247

 Net Cost/Watt: \$1.42/W
- Effective energy cost: \$0.041/kWh
 - 25 year life assumption
 - Utility charges \$0.11/kWh
- My savings so far (10.3 years): \$6,297



Installation



- My metal roof made installation easy no penetrations by using roof seam clamps
- Microinverters were attached to the rails



Westbrook House





Westbrook Load (no solar)



Utility Changes & Cost



- My utility made two major changes in 2020:
 - Allowed carryover of excess solar production kWh
 - Introduced several rate plans, including "free nights and weekends" starting in August
- "Free nights" plan works well with our daytime solar generation
 - Net positive energy during the day and used free energy at night

	Total	Day	N/WE					kWh	kWh	Bank	Bank
	Net	Net	Net		Elec		Base	Bank	Bank	After	Before
Date	kWh	kWh	kWh	Сс	ost (\$)	Fe	e + tax	Add	Used	kWh	kWh
8/14/20	197	(63)	260	\$	-	\$	24.40	63	-	63	-
9/14/20	243	(41)	284	\$	-	\$	24.40	41	-	104	63
10/22/20	86	(110)	196	\$	-	\$	24.40	110	-	214	104
11/14/20	57	(18)	75	\$	-	\$	24.40	18	-	232	214
12/14/20	194	(2)	196	\$	-	\$	24.40	2	-	234	232
1/14/21	224	63	224	\$	-	\$	24.40	-	63	171	234
2/14/21	284	59	284	\$	-	\$	24.40	-	59	112	171
3/14/21	208	13	208	\$	-	\$	24.40	-	13	99	112
4/14/21	(97)	(153)	56	\$	-	\$	24.40	153	-	252	99
5/14/21	(10)	(74)	64	\$	-	\$	24.40	74	-	326	252
6/14/21	97	(36)	133	\$	-	\$	24.40	36	-	362	326
7/14/21	152	(65)	217	\$	-	\$	24.40	65	-	427	362
8/14/21	(122)	(188)	66	\$	-	\$	24.40	188	-	615	427
9/14/21	218	(49)	267	\$	-	\$	24.40	49	-	664	615
10/14/21	160	(74)	234	\$	-	\$	24.40	74	-	738	664
11/14/21	85	(71)	156	\$	-	\$	24.40	71	-	809	738
12/14/21	23	(84)	107	\$	-	\$	24.40	84	-	893	809
1/14/22	274	46	274	\$	-	\$	24.40	-	46	847	893
2/14/22	216	25	216	\$	-	\$	24.40	-	25	822	847
3/14/22	(38)	(73)	35	\$	-	\$	24.40	73	-	895	822
4/14/22	21	(97)	118	\$	-	\$	24.40	97	-	992	895
5/14/22	142	(46)	188	\$	-	\$	24.40	46	-	1,038	992
6/14/22	275	(58)	333	\$	-	\$	24.40	58	-	1,096	1,038
7/14/22	67	(106)	173	\$	-	\$	24.40	106	-	1,202	1,096
8/14/22	436	63	436	\$	-	\$	24.40	-	63	1,139	1,202
9/14/22	414	54	414	\$	-	\$	24.40	-	54	1,085	1,139
10/14/22	(141)	(175)	34	\$	-	\$	24.40	175	-	1,260	1,085
11/14/22	136	(41)	177	\$	-	\$	24.40	41	-	1,301	1,260





Solar PV system real time monitoring



Solar PV with Battery



Solar PV & battery system real time monitoring



Results: Energy Efficiency



Solar Benefits (more payback)



- kWh price is less than half my current utility cost
- Return on investment System will pay for itself in less than a decade and continue to generate free electricity for at least another decade
- Lowest carbon content electricity and no air pollution
- Uses no water and is silent
- Distributed solar reduces the peak load on the grid
- Local generation means less energy loss
- No moving parts low or no maintenance
- Property tax exempt in Texas

Added Battery in 2022



- System became backward compatible with my 10 year old microinverters
- System is mostly for backup, but can be set to load shift if utility implements a time-of-day rate program
- Installed a 10.5kWh battery
 - Peak load of 5.7kW



Battery Addition



- When the grid goes down my power switches instantly to the battery power (islanding)
- Because our house is efficient the battery can power almost every load in the house



Published a Book





- The EFFICIENCY How to live and work better with less **PAUL WESTBROOK**
- My book has general efficiency tips, details on my house and solar PV system, and details on industrial efficiency

joyofefficiency.com