Feasibility study of HCPV system for use as an alternate energy source in residential units

Objective

To evaluate the application of HCPVs as indoor residential alternative power supply units.

Plan of Action

1. Design a 2-axis tracking HCPV unit to generate electricity for application in residential high-rises in densely populated cities.
2. Literature review to analyze various HCPV technology, minimal energy consuming 2-axis tracking and controls, and photodiode-based controllers for solar tracking during cloudy days.
3. Simulation to study feasibility of system considering other design parameters (such as shading, inverter selection, losses) and cost-energy analysis to determine LCOE.
4. Understand CPV's potential market value, cost and CO_2 savings.

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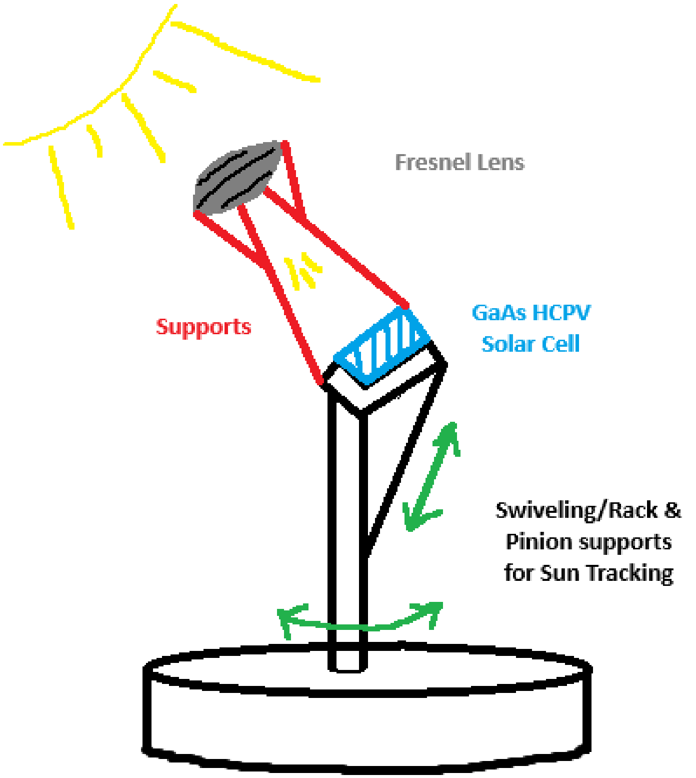
Design Parameters and Selection Critera

Based on our literature review, we have concluded on the following design specs:

Sr No	Components	Model/ Type	Capacity	Price
1	Fresnel Lens	Cracked Glass	for 1000x magnification	$10
2	GaAs HCPV Solar Cell (12 cm^2, 1000x)	CPV	320 Watts	$60
3	Inverter	Enphase 240V DC	384 Watts	$50
4	Stepper Motors (for robotic arms)		16 Watts	$20
5	Robotic Arms + Supports structure	3D Printed	-	$15
6	Microstep driver - Control	Mega 2560 Arduino	12 Watts	$50
7	Photodiode-based microcontroller (optional)		8 Watts	$15.46
			SUMTOTAL	**$205**



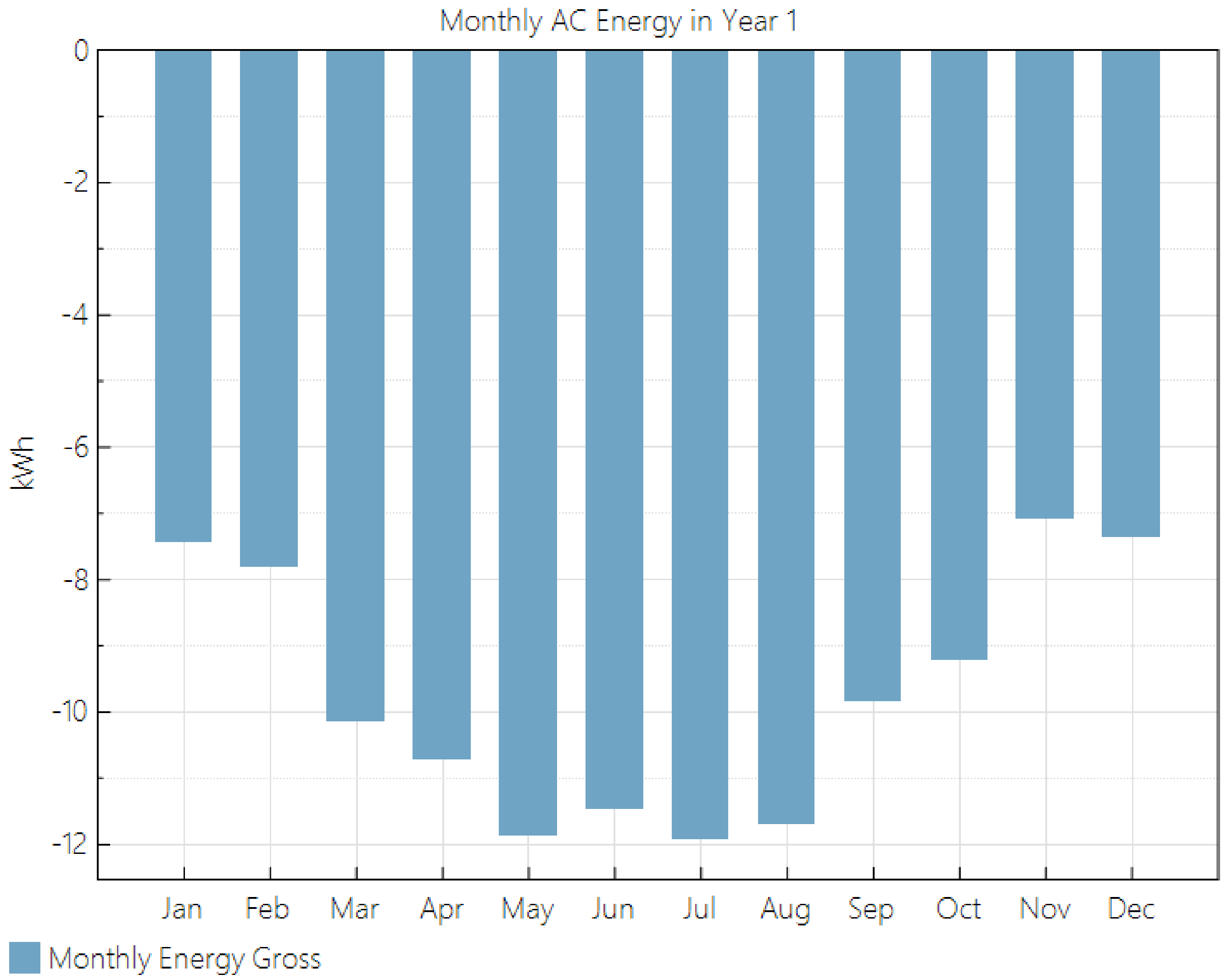
Annual Energy Savings for Single Installation

We calculated a HCPV system simulation on NREL's System Advisor Model (SAM).

We considered the following criteria:

1. **Location Data**: Phoenix Airport NSRDB WS#78208
2. **Shading Data**: South facing window in Ten01, Tempe. Data collection was done by Solmetric's Sun Eye Shading Analysis Calculator.
3. **Cell Sizing**: To achieve approx. 321.9 Watts output. This value was approximated based on an initial cost Vs application assumption. The cell would be approx. 12 cm^2 (4x3 cm).
4. **Concentration Ratio**: 1000x was assumed based on literature review, considering cell burnout to be least and price. Up to 3000x exist today.
5. **Losses**: Optical EF 0.9, Alignment and wind factor 0.1 each, tracking error 0.9, calculated module efficiency 29.806%. Up to 45% exist.

Annual Energy Savings for Single Installation (2) – SAM Summary



Metric	Value
Annual AC energy (year 1)	-117 kWh
DC capacity factor (year 1)	-4.1%
LCOE Levelized cost of energy	-28.00 ¢/kWh

- Analysis done for 10 years
- i.e., 117kWh/yr = 320 Whr/day
- 1 LED bulb uses 10.5 Watts.
- 1 typical Si solar panel can produce 1200 Whr/day

If prices from China are considered:

Metric	Value
Annual AC energy (year 1)	-117 kWh
DC capacity factor (year 1)	-4.1%
LCOE Levelized cost of energy	-13.00 ¢/kWh

Carbon Emission Savings

- The Total Carbon Emissions for Arizona in 2022 as cited by EIA https://www.eia.gov/electricity/state/arizona/ is 692 lbs/MWh.

Sources: U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report*, U.S. Energy Information Administration, Form EIA-861, *Annual Electric Power Industry Report*, U.S. Energy Information Administration, Form EIA-923, *Power Plant Operations Report* and predecessor forms.

- The Greenhouse Gas Equivalency calculator from EPA https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references calculates electricity reductions from the emissions factor as follows:

692 lbs/MWh of (Co_2 for Arizona) x (1 kg/2.20462 lbs) × (0.001 MWh/kWh) x 0.3219 kWh

= 0.101 kg of Co_2

Arizona State University

References

1. Duggan, G., Johnson, A.D., Davies, J.I., Nitz, P., Wiesenfarth, M., Jakob, P., Iankov, D., Rey-Stolle, I., Algora, C., Garcia, I. and Lombardero, I., 2018, September. ALCHEMI–A low cost, high efficiency, optoelectronic HCPV module for 1000× operation. In *AIP Conference Proceedings* (Vol. 2012, No. 1). AIP Publishing.
2. Katz, E.A., Gordon, J.M. and Feuermann, D., 2006. Effects of ultra-high flux and intensity distribution in multi-junction solar cells. *Progress in Photovoltaics: Research and Applications*, *14*(4), pp.297-303.
3. Horne, S. and Lasich, J., 2021. Concentrating photovoltaic systems and applications. In *Concentrating solar power technology* (pp. 357-397). Woodhead Publishing.
4. Goel, T. and Zhao, T. 2012. Solar tracking system and method for concentrated photovoltaic (cpv) systems. WIPO Patent No. WO 2012/149022 A2.

Appendix 1 – SAM Report

System Advisor Model Report

High Concentration PV	0.32 kW Nameplate	33.45, -111.98
LCOE Calculator		UTC -7

Performance Model

Modules	
Concentration ratio	1,000 X
Cell area	12 cm²
Module area	1.2 m²
Module capacity	321.9 DC Watts
Quantity	1 Modules
Total area	1.2 m²
Total capacity	321.9 DC Watts

Inverters	
<null>	
Unit capacity	384 AC Watts
Input voltage	38 - 43 VDC DC V
Quantity	1
Total capacity	384 AC kW
DC to AC Capacity Ratio	0.00
AC losses (%)	0.99

Array	
Modules per tracker	1 Modules
Trackers	1 Units
Shading	no
Soiling	yes
DC derate factor	0.93

Performance Adjustments	
Availability/Curtailment	0.12%
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)	
DNI	7.00, kW/m²/day
POA irradiance on cell	0.00, kW/m²/day
Gross from array	10 DC kWh
Net to inverter	0 DC kWh
Gross from inverter	0 AC kWh
Net to grid	-110 AC kWh
Capacity factor	-4.14%

Financial Model

Project Costs	
Capital cost	$205
Fixed operating costs	$5
Variable operating costs	$0

Financial Parameters	
Fixed charge rate	13.51%
Capital recovery factor	0.125
Project financing factor	1.065
Construction financing factor	1.012

Results	
LCOE (FCR Method)	-28 cents/kWh