DESIGNING PV-EV INTEGRATED RESIDENTIAL MICROGRIDS

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CURRENT TRENDS

+27% growth in annual energy inflation in Europe (Jan 2022)

Src: eurostat
The price of solar modules declined by 99.6% since 1976.

With each doubling of installed capacity the price of solar modules dropped on average by 20.2%. This is the learning rate of solar modules.

Data: Lafond et al. (2017) and IRENA Database; the reported learning rate is an average over several studies reported by de La Tour et al (2013) in Energy. The rate has remained very similar since then.
Solar PV is growing as fast as cell phones

Cell phone penetration (ITU) 1990=1
Cumulative Solar (EPIA) 2000=1

http://stats.areppim.com/stats/stats_mobile.htm
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POSITIVE FEEDBACK LOOP

The more you ship
The cheaper it gets
BUT...

Makes it challenging to meet demand
STORAGE

Decouples supply and demand

Allows
- Reliability
- Flexibility
SOLAR AND STORAGE ARE IN THE NEWS...

One down, five to go: Cook Islands begins shift to 100% solar and storage

Sunrun offers home solar and battery system in Florida

Australian network association seeks to unify solar and storage processes

Ikea Just Pushed Into Tesla's Turf

Tesla solar and Powerwall keep the lights on during Puerto Rico power outage

Companies are using California homes as batteries to power the grid

JLC Online
ARIZONA'S MANDALAY ADOPTS GRID-OPTIMIZED SOLAR-AND-BATTERY SYSTEMS

JACE STEWART TRANSPORTATION 05.16.18 06:12 PM

NISSAN'S FOLLOWING TESLA INTO SOLAR POWER AND HOME


sonnen-Engie partner up in France to sell solar-plus-storage through ‘shared vision’
BUT THERE IS MORE...
THREE PRAGMATIC ISSUES

System cost is going down, but still expensive ($10,000’s)

- How much to buy? (Sizing)
- How to place it? (Placement)
- When to charge and discharge the EV/home store? (Operation)
SIZING

**Tesla Preliminary Calculator**

Power Everything from Tesla

- Home Address
- Average Electric Bill: $165 / mo

**NREL ReOpt**

Step 1: Choose Your Focus
Optimize for financial savings or energy resilience?

- $ Financial
- Resilience

Step 2: Select Your Technologies

- ☑ PV
- ☑ Battery
- ☐ Wind
- ☐ CHP
- ☐ Chilled Water Storage

Step 3: Enter Your Site Data

- Site and Utility (required)
- Load Profile (required)
- Financial
- Emissions
- PV
- Battery
OUR APPROACH

Data-driven
Finds most economical combination to achieve a quality of service target: loss-of-load probability (LOLP)

Practical
Uses limited historical load and solar irradiance data

Robust
Confidence in meeting the loss of load target despite future being unknown
DATA
SYSTEM MODEL

LOLP probability that $P_{dir}(t) + P_d(t) < D(t)$

Operating policy Decide $P_c(t), P_d(t)$
PERFORMANCE TARGET

Target

- The system should **meet most of the load, most of the time**
- The probability that the system meets over $\theta$ fraction of the load over any fixed length period should be lower bounded by $\gamma$

\[
Pr\left( \sum_{t}^{T} (P_{dir}(t) + P_{d}(t)) \geq \sum_{t}^{T} D(t)\theta \right) \geq \gamma
\]
COUPLING

Placement <-> Sizing <-> Operation
IDEA: SIMULATION OF OPERATION FOR EACH SIZE

Input: trace pair $<S_i, D_i>$, target, operating policy

Method:
- For a given $B$ and $C$, simulate the process of power flowing through the system
- Search for cheapest $B$ and $C$ that meet target LOLP
- Tradeoff between $B$ and $C$ (why?)

Output: $<B, C>$ pair
ALGORITHM

Subsample PV/load traces of length T

- Computer (B,C) Pareto frontier for each subsample
- Chebyshev bound for robustness
SINGLE-ROOF SIZING ALGORITHM

- Start from max PV
- Find minimal battery
- Decrease PV allocation by one unit
- Repeat; find a Pareto Frontier
SINGLE-ROOF SIZING ALGORITHM

- Repeat for all subsamples
- Variability due to seasonality
SINGLE-ROOF SIZING ALGORITHM
MULTI-ROOF SIZING ALGORITHM

Subsample PV/load traces of length $T$

*Minimal cost sizing tuples* for each subsample

*Multivariate* Chebyshev bound for robustness
MIN-COST FINDING
CHEBYSHEV BOUND
ROBUSTNESS

\[ \varepsilon = 0.10 \]

\[ \gamma = 0.85: \text{4.1\% sizings with loss > 10\%} \]
IMPACT OF EVS

Depends on how long they’re present at home and charging style

- If working from home, they’re present longer
OUR SOLUTION FOR POST COVID EV TRACES

Typical commuter

Hybrid

Typical WFH

Figure 5.5: The T1, T2 and T3 profiles.
EV CHARGING APPROACHES

\[ t_{\text{charge}} = t_{\text{arr}} \]

\[ t_{\text{charge}} = t_{\text{dep}} - K \]

\[ t_{\text{charge}} = t_{\text{ch}} \]
Impact of WFH on the design

- Essential to consider commuting patterns
- Increase in WFH leads to cheaper and more efficient systems (approx. 30% cost decrease)
Potential of bidirectional EVs

• With 2 WFH days per week, storage is not needed in some cases
• Adding more WFH days does not significantly change the microgrid design requirements
• Heavily depends on location, individual consumption patterns,...
PLACEMENT
CONCLUSIONS

Solar, storage, and EVs are here to stay
Sizing, operation, and placement are challenging research problems
Our algorithms provide data-driven, robust solutions
Solar Panel and Battery Size Calculator

Welcome!
This calculator is intended for homeowners and small to medium businesses to determine how many solar panels and how large a storage battery to buy to achieve a certain level of grid independence, based on your location, solar panel parameters, and electricity usage. The algorithm accounts for multiple roof segments.

To use this calculator, please prepare the following:
- Your location, in terms of longitude and latitude. Later this page you can also detect your location with your IP address or enter your city.
- Solar panel parameters, including the tilt and azimuth of your solar panel, and what types of panels you plan to install. See detailed instructions on page 2. (The parameters and instructions are provided by PVWatts).
- Your electricity statement, up to a year for each month. We are interested in how much electricity (in kWh) you used for each month during the past year, as well as (optionally) the electricity cost for the last entire year.
- Your local system costs for solar panels and batteries. We listed out some sample prices per watt in the US but different regions have different costs. Everyday provides general instructions and example prices.

Your Location
Location: Your location is needed to compute how much electricity your solar panels can generate. Enter your locations using any of the following:

Auto-fill location using your IP address: Detect Location

OR

Enter your city:

OR

Enter your latitude and longitude:

Manual input PV Generation Parameters Instead

Solar Panel Position
Tilt: The tilt angle is the angle from horizontal of the solar panel. The optimal angle, if possible, is the absolute value of the latitude of your location. See below for detailed instruction.

Azimuth: For fixed arrays, the azimuth angle is the angle clockwise from true north describing the direction that the array faces. An azimuth angle of 0° is for a south-facing array, and an azimuth angle of 180° is for a north-facing array. See below for detailed instruction.

Enter your number of roof segments:

Enter your Tilt and Azimuth:

Tilt in degrees

Azimuth in degrees

Solar Panel System Losses
System losses: The system losses account for performance losses you would expect in a real system that are not explicitly calculated by the PVWatts model, mainly soiling. The system losses account for performance losses you would expect in a real system that are not explicitly calculated by the PVWatts model equations. Click on the info icon for detailed instruction.

System losses [%] [2.00]

Solar Panel Type
Module Type: The module type describes the type of photovoltaic cell used in the solar panel. See below for detailed instruction.

Array Type: The array type describes whether the solar panel in the array is fixed, or whether they move to track the movement of the sun across the sky with one or two axes of motion. See below for detailed instruction.

Module Type:

Array Type:
TESLA BLINKED!

Power Everything from Tesla

Home Address

Average Electric Bill
$165 / mo

How to use the Interactive Layout Experience

For eligible solar panel layouts, select ‘Review’ under ‘Your System Design,’ then ‘Request a Layout Change’ to be taken to the Interactive Layout tool in your Tesla Account:

- De-select a numbered roof area to remove solar (the roof area will turn red) or select a roof area to add solar (the roof area will populate with solar panels).
- You can toggle between the layout and your roof’s sunlight exposure and your energy consumption versus system production using the tab under the layout.
- A notification will be sent once your redesign is ready for review in your Tesla Account.
REFERENCES


