Decentralized Photovoltaics: Autonomie, Self-Consumption and Reduction of Grid Loading through Electrical and Thermal Storage

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Topics

• Network and Local Perspective: Balancing Generation and Load

• Local Balance of Energy:
  • PV, Electrical Appliances, Electrical Heating
  • Resulting Self-Consumption & Autonomy

• Storage Control for reduced Grid-Loading

• Cost and Amortization
  • Feed-in tariffs in Germany (current proposal)
  • Self-consumption increases internal rate of return (IRR)
Balancing Generation and Load – Storage as Buffer

Large scale power plants
- Fossil & nuclear
- Off-shore wind

Distributed fluctuating generation
- Photovoltaics
- On-shore wind

Local generation, storage and load management

High voltage transmission

Network control & grid stability

Distributed storage and balancing generation
- SNG
- Natural gas
- Bio gas
- Battery storage
- Pumped hydro

Regional control & tariffs

Low voltage distribution grid
A Local Perspective - PV with Storage
Enabling Self Consumption, a Degree of Autonomy and Grid Load Reduction

Solar self consumption
• which part of the PV generation is consumed locally.

\[ \frac{E_{PV,sc}}{E_{PV}} \]

Autonomy
• which part of the total energy demand is produced locally

\[ \frac{E_{PV,sc}}{E_{total}} \]

Grid Load Reduction
• smart storage algorithms can reduce peak value of power-feed into the grid and change times of consumption from the grid
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Balance of Energy Input and Loss

Energy Input
- Solar Radiation
  - Electricity produced through PV
  - Heat input through windows
- Electricity consumed from Grid

Energy Consumption
- Electricity for household appliances
- Electricity for Heating purposes
  - Hot water
  - Spacial heating

Thermal energy demand
- proportional to temperatur difference
- decreasing with improved building standard
- decreased by solar radiation and heat produced by appliances
- increased by hot water demand

Storage
- Electrical Battery Storage
- Thermal Storage through Hot Water Tank

Thermal demand linked to electrical demand through electrical heating (e.g. heat pump)
Calculation of the Energy Balance – Yearly Time Series

Input values as yearly time series
- Solar Irradiance
- Outside temperature
- Electrical load from appliances (yearly sum 3.900 kWh/a)
- Hot water demand

Additional input parameters
- Size of the PV installation
- Building standard – specified by the specific heat demand
- Size of house $A_N = 140 \, \text{m}^2$, 4 inhabitants
- Heat pump ($\eta_{HP} = 40\%$, $T_{Source} = 10 \, ^\circ\text{C}$)
- Storage volume of electrical storage
- Storage volume of hot water tank
- Set-point temperature within in the tank ($35\, ^\circ\text{C}$ / $50\, ^\circ\text{C}$)
- Storage-control algorithm (e.g. excess of PV will heat up to $53\, ^\circ\text{C}$)
## Result: Yearly Demand of Energy

<table>
<thead>
<tr>
<th>(A_N=140 m²)</th>
<th>Unit</th>
<th>Zero energy house</th>
<th>Standard of 2009</th>
<th>Standard of 1995</th>
<th>Standard of 1975</th>
</tr>
</thead>
<tbody>
<tr>
<td>standardized heat load</td>
<td>kW</td>
<td>2,5</td>
<td>5,0</td>
<td>7,3</td>
<td>11,5</td>
</tr>
<tr>
<td>specific heat demand</td>
<td>kWh/m²a</td>
<td>30</td>
<td>75</td>
<td>120</td>
<td>200</td>
</tr>
<tr>
<td>yearly heat demand</td>
<td>kWh_th/a</td>
<td>4,300</td>
<td>10,500</td>
<td>16,800</td>
<td>28,000</td>
</tr>
<tr>
<td>electrical energy for the heat pump</td>
<td>kWh_el/a</td>
<td>1,400</td>
<td>3,200</td>
<td>5,100</td>
<td>8,700</td>
</tr>
<tr>
<td>yearly coefficient of performance</td>
<td></td>
<td>3.1</td>
<td>3.3</td>
<td>3.3</td>
<td>3.2</td>
</tr>
</tbody>
</table>

- energy for electrical household appliances | kWh_el/a | 3.900

Building standards as required by the respective German energy conservation regulation for buildings renovated and built at or after the given year; www.enev-online.de
Photovoltaic – Systems
Electrical Energy Demand and Heat Demand

Rate of Local Generation
• Ratio of locally generated energy to total of consumed energy

HP-SPF: Heat pump seasonal performance factor
Photovoltaic – Systems
Electrical Energy Demand and Heat Demand ➔ Grid View

Rate of Local Generation
• Ratio of locally generated energy to total of consumed energy

Solar Self Consumption SC
• Ratio of self consumed PV to locally generated energy through PV

HP-SPF: Heatpump seasonal performance factor

HP-SPF: Heatpump seasonal performance factor

Heat Demand
Balance of Electrical Energy

E_{PV}
E_{consumption}
E_{feed-in}
E_{th,ges}
E_{el,ges}
E_{feed-in}
E_{consumption}
SC @ concurrent generation
SC @ concurrent generation

Thermal Storage
Heat Pump
Elektrical Storage

E_{consmption}
E_{feed-in}
E_{PV}
Result: Yearly Balance of Energy
Case 5500 kWh/a from PV; load for appliances 3900 kWh/a

Non electric heating system

Electrical heating using heat pump and thermal storage
Yearly Balance of Energy with added Battery Storage

Case 5500 kWh/a from PV; load for appliances 3900 kWh/a

Non electric heating system
Size of Battery 5 kWh

Electrical heating using heat pump
Size of Battery 5 kWh

Effect of battery +25%

PV production
Electrical energy for appliances
Self-Consumption

Building standard

- 12 - 03.07.2012 J.Binder
Yearly Balance – a View from the Grid
Excess PV Generation fed into Grid; missing energy consumed from Grid

PV = 5500 kWh/a no battery

For further details see upcoming publication:
Solar Self Consumption depends on the Heating Load and the Thermal Storage Volume

PV = 5.500 kWh/a, without batterie

- Heat pump with hot water (HW) preparation and thermal storage (1000-2300 l)
- Heat pump with HW & therm. storage (660 l)
- Heat pump without HW & therm. storage (660 l)
- Heat pump without HW, without storage
- Without heat pump, electrical appliances only
Dependance on PV-System and Battery - Size

- a battery storage capacity of 5 kWh increases autonomy and SC approximately 30% in the case without a heat pump.
- In case of a connected heat pump in order to maintain a given rate of local generation, the PV system size is increased. Nevertheless the autonomy will decrease, due to the missing solar irradiance during the predominant times of heat-pump operation (winter). The influence of the battery is reduced, since thermal storage is present.
Self-Consumption for measured Load Profiles calculated based on 10-min load data from 89 households

Data and calculation is provided by the French partner INES-CEA within the Sol-Ion project
- 4 modules = equal 5,3 kWh of used battery capacity
- calculated with irradiation data of Kassel, Germany

Increase in self-consumption
0% - 30%
Summary: PV with heat pump and Storage
Effect on Self-Consumption and Autonomy

- The total (electrical and thermal) energy consumption of a building is analysed
- Use of a heat pump and thermal storage allow to increase SC
  - from 30 to 40% for buildings of high building standard
  - to 65% for buildings with low building standard
  - Values depend on the ratio of the PV generation to the total load and the user load profile
- For the examined profiles a battery capacity of 5 kWh increased autonomy and SC by ~ 30% if only the electrical appliances where supplied with PV generated electricity and by ~ 10% if a heat pump was used in a house with moderate heating load.
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  • Self-consumption increases IRR
Storage to Reduce Grid Loading
Time Series of Grid Feed-in Levels without SC plotted for one Year
1. feed-in levels from a real PV system without SC (15-min values, 2010)
2. remaining feed-in after simulated SC in a Zero Energy house with heat pump
3. same as (2), but with a battery capacity of 5 kWh. Peak levels are not influenced.
4. same as (3), but with delayed battery charging. Duration of peak levels is reduced.
5. same as (4), but heat pump is switched on, if the feed-in level would otherwise exceed the 2500 W limit. This is done until the temperature reaches 80°C.
Delayed Charging of Battery

Algorithm: the set-point for the maximum State of Charge (SOC) of the Battery is linearly increased from 9:00 h to 14.00 h.
Time Series of Grid Feed-in without Self-Consumption Plotted for one Year (15-min values)
Time Series of Grid feed-in after Self-Consumption, with local Battery of 5 kWh
Grid feed-in after Self-Consumption, with local Battery Storage and additional thermal Buffering
Summary: Storage Control for reduced Grid Loading

• Maximum grid-injections levels can be reduced by
  • delayed charging of the electrical storage and
  • using the thermal storage as an additional buffer to cut peak injection levels
• For an electrical storage volume of 5 kWh and a thermal storage of 1000L hot water (which are a suitable sizing for a single family building of high building standard)
  • Maximum grid-injections levels have been reduced to 55% of the level without self-consumption and storage
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German Feed-In Tariff
Current Proposal – Status 27.06.2012

- Valid on 01. April 2012
  - 0 – 10 kWp: 19,5 ct/kWh
  - 10 - 40 kWp: 18,5 ct/kWh
  - 40 - 1.000 kWp: 16,5 ct/kWh
  - 1-10 MWp: 13,5 ct/kWh
- Monthly Degression depends on installations during last 12 months
- yearly installations of 2.5 – 3.5 MWp pose the intended baseline and yield 1% degression

communication of BSW solar – 27.06.2012
Feed-in Tariff versus Self-Consumption

Electricity prices:

- **Household – Germany**: ~ 21.6 ct/kWh (without 19% VAT)**
  
  ** source BDEW 04.05.2012 – for 3500 kWh yearly consumption
  
  - 55% are for production, transport and sales of energy → 14.1 ct/kWh
  - 45% are for tax, EEG surcharge (3.59 ct/kWh in 2012) et.al.
  - the total increase of 50% since 1998 is mainly driven by tax and surcharges

- **Household - France**: 10 – 12 ct/kWh (without 19.6% VAT)

German case for new installation up to 10 kWp in July 2012:

- **Feed-in**: 18.9 ct/kWh for 20 years
- **Self-Consumption**: 21.6 ct/kWh raising by e.g. 3% per year (average 2012-2032)

  **average 2012-2032**: 18.9 ct/kWh for 20 years

  **average 2015-2035**: 30 ct/kWh average over 20 years

  **average 2015-2035**: 33 ct/kWh
Return of Invest within 20 Years

PV production cost, if total generation is sold: → 16.8 ct/kWh**

CASE: no feed-in tariff and
30% Self-consumption for appliances
+26% Self-consumption for heating purposes: → 30 ct/kWh

* Tariff July 2012 for PV system 0-10 and 10–40 kWp, respectively
** 1.776 €/kWp, 4% interest rate and 2% yearly maintenance & insurance
Important Factors:

- lifetime of the battery
- Equivalent full cycles passed through the battery per year
- **System cost** (incl. Inverter) for each kWh of used capacity

Example:

- 20 years for Li-B.
- 240 cycles
- 2000 €/kWh

Resulting cost per stored kWh without financing:

\[
\frac{2000}{(20 \times 240)} = 42 \text{ ct/kWh}
\]

Cost per stored kWh including financing (4% interest rate):

\[
\frac{2000}{(20 \times 240) \times (1+0.04)} = 62 \text{ ct/kWh}
\]

Battery Storage: cost per kWh stored energy

Until 2015 → Cost / 2
Until 2020 → Cost / 3

30 ct/kWh reached ~ 2015

* Cost is battery only – nominal capacity in kWh; system might use battery only to 50% for lifetime reasons → cost per used kWh doubles
Summary: PV with heat pump and storage
Self-consumption, Autonomy and Grid Load Reduction

- Single family home, 4 person, PV-installation 5500 kWh
  - Self Consumption (SC) ~ 30%
- Increase of SC through heat pump – without battery
  - from 30% to 40% for high building standard
  - from 30% to 65% for low building standard
  - thermal storage volume of ≥ 1000 L advisable
- Self-consumption and autonomy with battery of 5 kWh capacity; increased by
  - ~ 30% using electricity for appliances only
  - ~ 10% using heat pump and thermal storage
- Grid Load Reduction
  - feed-in limited to 55% of the previous maximum, through self-consumption and added storage control algorithms for the battery and thermal storage.
Summary: PV with heat pump and storage
Self-consumption, Autonomy and Grid Load Reduction

• Electrical heating allows for effective load management
• **Advantage for the owner and local user**
  • increase of Self-Consumption and Autonomy in the light of Grid-Parity
  • replacement of increasing energy costs by a fixed Invest
• Invest Costs
  • heat pumps: viable in combination with new building or replacement of current heating → low additional Invest
  • choose a sufficient storage size → low invest
  • battery storage → still high invest
• **Advantage for distribution network operator**
  • intelligent storage control reduced network load
  • storage allows for variable times to purchase electricity
  • **participate in storage cost / incentive through tariffs!**
Decentralized PV with heat pump and storage
Self-consumption, Autonomy and Grid Load Reduction

Thank you!

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