Dimensioning of decentralized photovoltaic storages with limited feed-in power and their impact on the distribution grid

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1. Introduction

Germany is a worldwide role model in expanding renewable energies. However, in a growing number of cases grid operators deny the connections of new PV systems due to grid constraints. Therefore, in a first step, the capability of German distribution grid to transport feed-in power was analyzed in chapter 2. These investigations were done in the course of a master students project in electrical engineering at Cologne University of Applied Science in 2012. The results are published in a journal article [10].

As another limitation of the expansion soon the lack of storage will appear. Decentralized storages can be a major contribution to it. To stimulate their growth, and to allow more PV systems connected to the distribution grid, a support model has been proposed by the Solarenergie-Förderverein Deutschland e.V. (SFV, "The German Association for the Promotion of Solar Power") [8]. This model includes a limitation of the feed-in power to 30% of the PV peak power, the use of a battery and a financial compensation. This model is investigated in chapter 3.

A further strong motivation for batteries in combination with PV is the optimization of the self-consumption. Since some time, grid parity of PV energy is by far exceeded. In Germany, consumer cost of electricity is up to 29 €ct/kW, while the feed-in tariff for PV energy, is in the order of 14 €ct for residential sized PV systems. Therefore, the self-consumption of PV energy pays back. In chapter 4, such battery use is investigated in detail. It was the subject of a bachelor thesis[11], where details can be found.

To achieve a grid benefit, the storage operation for optimized self-consumption must be combined with a feed-in limitation. This is also implemented in the recent subsidizing program for decentralized PV batteries in Germany [5] with a feed-in limitation of 60% of the PV peak power. The combination of both operation modes is investigated in chapter 5.

2. Feed-in capabilities of the distribution grid

2.1. Assumptions and specifications for the simulation

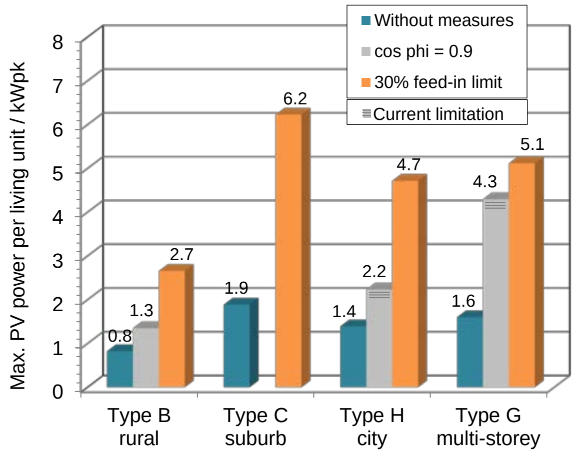
Distribution grids in Germany differ in different settlement area types. This work relates to a classification of settlement areas as given in ([1], see also [2]). From this list four exemplary types are selected: Type B: Rural area, Type C: Typical suburb area with one and two family houses, Type H: City area and Type G: multy-storey buildings. The exemplary power grid structures as proposed by J. Scheffler [1] are used to analyze the grid situation. Details about the grids can be found in his work. To simulate the power consumption, standard load profiles by Eon [3] are used and scaled to 3000 kWh/a for each living unit ("Wohneinheit", WE). To simulate the PV feed-in a real measured profile of the year 2011 of a typical residential PV system is used [6]. Equipment like transformers and power lines are loaded with maximum 100% of the rated power and current. Furthermore, according to [7] the voltage at an arbitrary node with consideration of the total PV feed-in power must remain within a +/-3% margin compared to the case without feed-in.

The grid capability was investigated for the grid without any measures, but also with additional measures: By drawing inductive power the voltage can be lowered. According to [7] new PV systems must be able

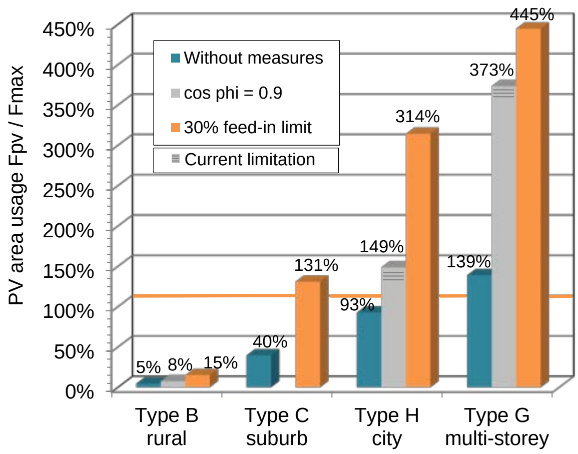
to draw inductive power with a power factor of cos φ = 0.95 or cos φ = 0.90 (>13 kWpk).
Another measure is to limit the feed-in power of PV-systems (see introduction in chapter 1). The impact of this measure on the grid capability has also been considered here
Electrical simulations were performed using the software NEPLAN, Vers. 5.5, 2012 [9]. First, load flow calculations were done for the 8. Aug. 2011, which was identified as the day with the largest grid load. From these simulations the most un-favorite conditions for voltage, lines and transformer were derived and then summarized.

2.2. Results

The most important results from the electrical simulations are summarized in Figure 1a. It shows the maximal possible installed PV power per living unit for different settlement areas. In most cases, the 3% voltage criterion was the limitation reason. Clearly, rural and suburb areas have a lower potential for feed-in as city areas. In these areas the typically longer lines soon result in higher voltages exceeding limits. Drawing of inductive power gives a slight improvement. But especially in rural areas, the improvement is minor, and in city areas inductive power soon leads to limiting line currents. The most reliable possibility for extension is the feed-in limitation. In all areas about 3.3 times more PV peak power can be installed.



a)



b)

Figure 1: a) Maximal possible PV power per living unit. b) Maximal possible PV area usage.

In the different settlement areas, a different amount of PV area is available as listed in [10]. Figure 1b illustrates, how much of this available PV area can be used, before the grid is overloaded. Values below 100% (see horizontal line) mean that only a part of the available PV area can be used. As clearly visible, in rural area only a small fraction of the area potential can be used. Without additional measures, only 5% can be used. With feed-in limitation, the usage of the potential can be tripled. Obviously, only a grid enforcement can exploit the full potential in rural areas. In suburb areas, feed-in limitation can lead to a full usage of the available PV area. Contrary, in city areas and multi-storey building areas the full PV area potential can be used already now without additional measures.
Concluding, in city areas PV feed-in is not limited. In suburb and rural areas feed-in limitation using distributed storages has the most effect to exploit the PV area potential in these regions.

3. Storage for feed-in limitation

The PV feed-in limitation obviously reduces the impact of PV generation on the distribution grid. Here, the consequences for the operation and optimization of such a PV system including battery are discussed.
Figure 2 illustrates the basic idea of the operation with feed-in limit and battery. When the PV system generates more than the 30% of its peak power (assumed as limit here, red curve), only 30% of the peak

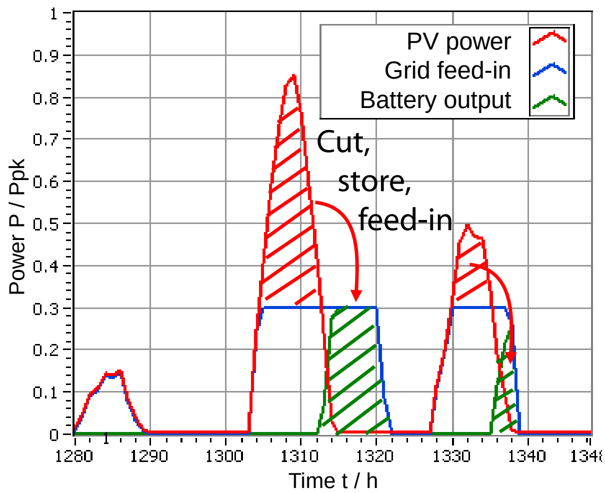


Figure 2: PV power and feed-in with storage

power is fed into the grid (blue curve) and the remaining energy is stored in the battery. If the PV power is less than the limit, the battery is depleted (green curve), as long as the battery has energy.

The investigations were done with the same measured PV data set for the complete year 2011 [6] as in the previous chapter. All calculations were done with a software written by the author in computer language Labview. The software simulates the behavior of the PV system like shown in Figure 2, but for a whole year and for a certain set of parameters. Then the simulation is repeated with changed parameters. Finally, the resulting key values of the simulations are displayed in diagrams as functions of the varied parameters. A charging efficiency of 90% and a discharging efficiency of 90% leading to a round trip efficiency of 81% are assumed.

3.1. Results

As reference the turquoise curve shows in Figure 3 the amount of energy, which can still be fed into the grid, if the cut-off energy is *not stored*. With a feed-in limit of 30% still about 2/3 of the maximal possible energy can be used in the grid.

The orange curve shows, how much energy can be fed-in with a sufficient large storage. The curve is calculated with a battery size of 1000 kWh/kWpk, which can be considered as “large”. It is obvious that even with a “large” battery the available energy is not fully available for the grid. The missing energy relates on the one hand to the losses during charging and discharging. Below a limit of 20% the limit is lower than the average power of the PV system and then no point of time exists, when the cut-off and saved energy can be fed back to the grid.

The next Figure 4 allows optimizing the battery size for the application in a feed-in limitation PV system. The figure shows the annual feed-in energy, which is related to the annual generated PV energy. A value of 100% relates to the whole annual PV generation fed into the grid. The values are shown as functions of

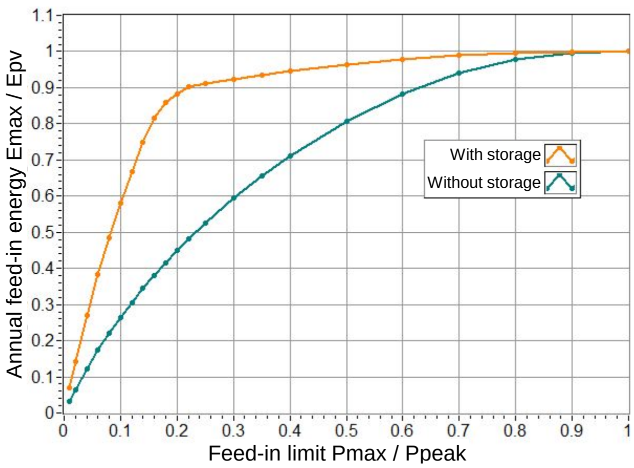


Figure 3: Yearly feed-in solar energy: Cyan: Without storage. Excess energy is lost. Orange: With “large” storage.

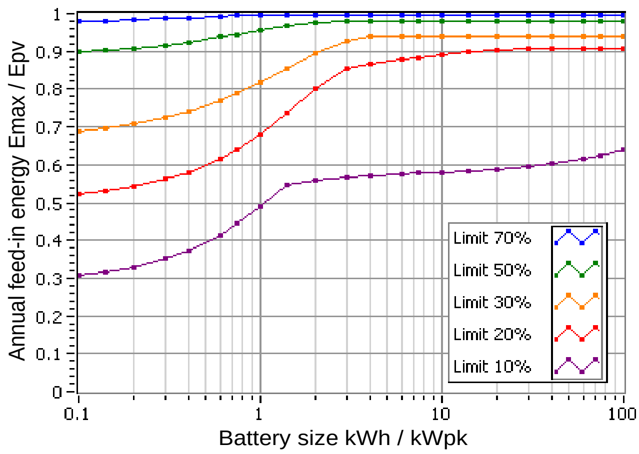


Figure 4: Fed-in energy as function of the battery size with feed-in limit as parameter. Battery size is scaled the PV peak power.

the battery size, which is related to the size (peak power) of the PV system. The different colored curves relate to different feed-in limits. The orange curve relates to a feed-in limit of 30%, corresponding to the SFV proposal.

For small batteries, only a fraction of the available PV energy can be fed-in. Above a certain battery size no increase of the feed-in energy is possible. With a 30% feed-in limit, the threshold value of the battery size is about 3 to 4 kWh/kWpk. Increasing the size brings no further benefit. If it is smaller, more energy gets lost. Therefore, this size can be considered as the optimal battery size for this application. Apparently, it is more or less independent of the feed-in limit.

Despite the battery, the majority of the energy is directly fed into grid. With a 30% limit, only about ¼ of the total energy is passed through the battery.

4. Storage for self-consumption of PV power

This chapter investigates the optimal dimensioning for a battery used to improve the self-consumption of PV energy.

4.1. Operation mode

If a battery is used to optimize self-consumption, the operation mode uses the following order of priority:

- During sunshine: 1. Self-consumption, 2. Load battery, 3. Grid feed-in.
- During dark: 1. Discharge Battery (No grid feed-in), 2. Grid operation

Figure 5 shows power profiles and charging state profile of a PV system with battery for exemplary days to illustrate the operation modes. The orange curve shows the PV power generation. The blue curve shows the load consumption. The feed-in power to the grid is shown in gray. The turquoise curve corresponds to the charging state of the battery (right vertical axis).

In range ① the PV power is large enough to supply the load and to charge the battery. In range ② there is no PV power and the battery is discharged by the load. Note that there is no discharge to the grid. Contrary to the feed-in limit operation mode the battery is kept charged as much as possible.

Range ③ shows the state, when the battery is full at noon. Then, nearly the full PV power is fed into the grid.

This shows that a battery operated to optimize self-consumption has *no benefit for the grid*, because there are still times, when nearly the full PV power is fed in!

4.2. Measurement data and simulation

As in the previous chapter, the investigations were done with the same measured PV data set for the complete year 2011 [6]. The system generates approximately 1000 kWh/a/kWpk, which is used as scaling constant in the simulations. All calculations were done with a software written by M. Roskosch in computer language Labview. The software first simulates the behavior of

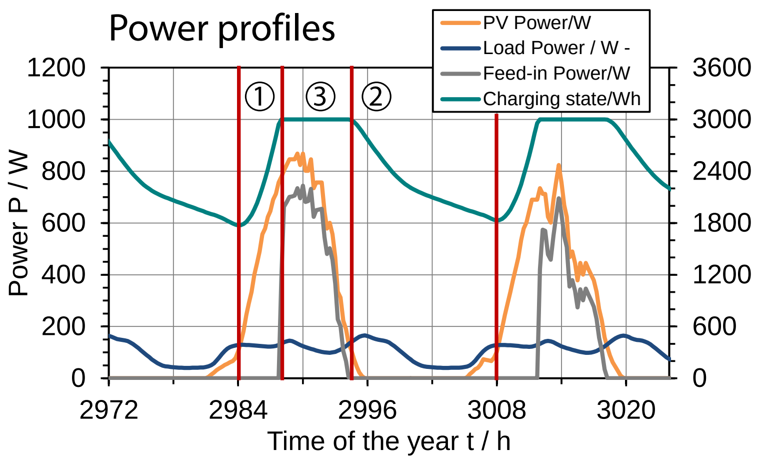


Figure 5: Power profiles and charging state profile of a PV system with battery for improved self-consumption at exemplary days. Parameters: Annual consumption 1000 kWh, PV size 1.1kWpk, battery size 3 kWh.

the PV battery system for a whole year and then repeats it with changed parameters to finally display the resulting key values. A charging efficiency of 90% and a discharging efficiency of 90% leading to a round trip efficiency of 81% are assumed. To represent the load, the standard load profile H0 by Eon [3] is used, unless otherwise noted. The initial battery status was set equal to the end of year status for all simulations.

4.3. Results

4.3.1. Autarky

As primary figure of merit (FoM) the grade of autarky is investigated. The grade of autarky is defined by the amount of consumed energy provided by the PV system related to the total consumption.

Figure 6 shows the grade of autarky as function of the size of the PV system. The orange curve relates to a system without battery. As can be seen, only about halve of the needed energy can be provided by the PV system, even with a very large one. This is, because even the largest system doesn't generate power during dark. This curve relates to a standard load profile. However, it is strongly dependent on the actual load profile (not shown), and the grade of autarky can be improved by matching consumption to the PV generation.

The blue curve relates to a system with a "large" battery. As soon as the PV system's annual generation matches the consumption, autarky can be achieved.

For small PV systems, which generate less than 20% of the consumption, a battery makes no difference. The PV generation is always low enough to be used instantly.

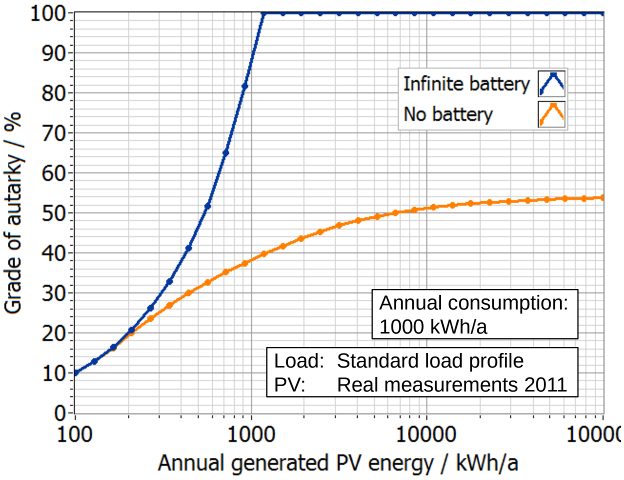


Figure 6: Grade of autarky as function of the size of the PV system.

Figure 7 shows the grade of autarky as a function of the battery size. The different colored curves relate to different sizes of the PV system. All values are calculated for an annual consumption of 1000 kWh. This figure allows discussing the optimal size of a battery for self-consumption.

As discussed with the previous Figure 6, a small PV system (gray curve) doesn't need a battery. With a somewhat larger system, which generates about halve of the annual consumption (turquoise), a battery can improve the grade of autarky.

The blue curve relates to a PV system capable of just generating the annual consumption. With a very large storage, autarky can nearly be achieved. The small difference is due to losses in the battery. Without battery, only a grade of autarky of 40% can be achieved. Increasing the storage size increases the grade of autarky, but only up to a certain battery size of approx. 2 to 3 kWh. Then, a further increase of the battery size does increase the autarky only marginally. Only, if the battery size becomes two orders of magnitude larger, the grade of autarky increases again and autarky can (nearly) be achieved. A larger PV system of 3000 kWh/a behaves similar. Only a very oversized PV system, which generates 50 times as much energy as needed, achieves full autarky with a comparable small battery of 2 kWh.

The explanation for the curves of the medium sized PV system could be found analyzing the profiles in detail. A storage of 2 to 3 kWh relates to a daily storage. It is capable to store the daily amount of

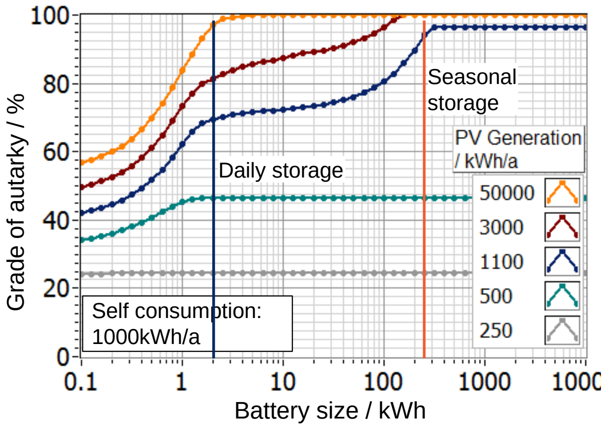


Figure 7: Grade of autarky as a function of the battery size with annual PV generation as parameter. Scaled to consumption of 1000 kWh.

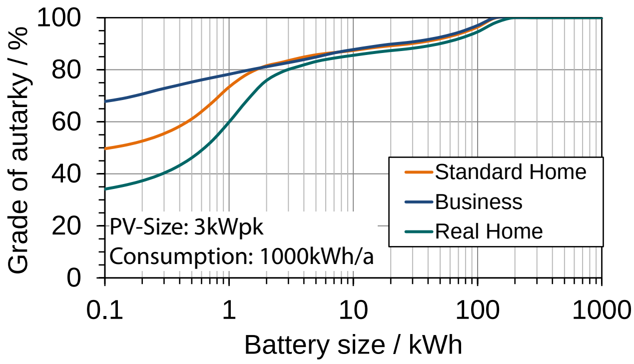


Figure 8: Autarky for different load profiles.

consumption and therefore levels out the unsteady PV generation overt the day and the missing one during night. During summer, where the daily PV generation meets or exceeds the consumption, this helps to improve the self-consumption of the PV energy. However, during winter, the daily PV energy is not sufficient to supply the demand.

To achieve a full autarky, a sufficient autarky in winter is necessary. This can be achieved by storing excess energy in summer for the winter, which makes a very large seasonal storage necessary. Else, the PV system is so large that it can provide sufficient daily energy also in winter. Both solutions to achieve full autarky are very expensive.

Concluding, a daily storage would be the recommended size.

The size of this daily storage is only dependent on the annual (to be precise: daily) consumption, but not on the size of the PV system. This can easily be understood, since the storage is used to provide energy for the consumption, and not to save energy of the PV system as in the feed-in limitation operation mode.

As mentioned, the grade of autarky without storage is dependent on the load profile of the consumption. It is shown for three different exemplary load profiles in Figure 8. The first profile “Standard Home” is the standard load profile used in the previous figures. The second “Standard Business” is the standard load profile for daily business G1 provided by Eon [3]. The third “Real Home” is a measured profile. The data was available for one week. To obtain an annual profile, it was duplicated and scaled sinusoidally like the standard load profile to account for difference in summer and winter. The figure shows: As soon as the battery size reaches the size of a daily storage, the three curves match. This seems logical, since a daily storage levels out the differences of the profiles during the day.

Therefore, the optimal dimensioning of the battery is very simple: It relates to the annual consumption with a constant of about 2 kWh battery size per 1000 kWh consumption, independent of the load profile.

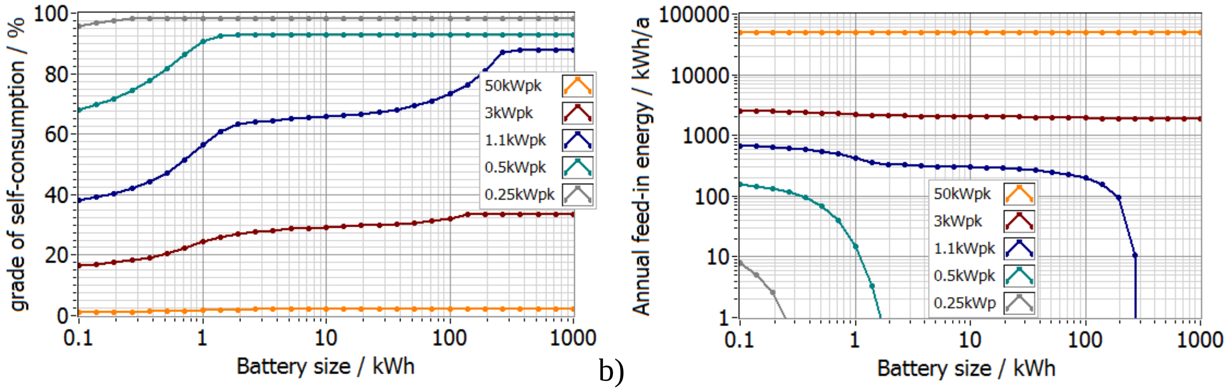
4.3.2. Grade of self-consumption and feed-in energy

Another figure of merit is the grade of self-consumption. It is defined as the amount of PV generation used for consumption related to total PV generation. This figure of merit describes how beneficially the PV power is used (assuming self-consumed PV power as beneficial).

Figure 9a shows the calculation results as a function of the battery size with the PV size as parameter for the different colored curves. In addition, Figure 9b shows the yearly feed-in energy into the grid.

The results of the grade of self-consumption look opposite to the previous results. But as mentioned, the energy of a small system (gray) is instantly used, and therefore, a high grade of self-consumption is achieved. Only a negligible amount is fed into the grid (Figure 9b). Contrary, most energy of the large, oversized PV system is fed in to the grid. Only a small fraction of the generated PV energy can be used for the consumption, because it is so oversized.

Concluding, to obtain a high grade of self-consumption of the PV system, it should be small. However, then only a reduced grade of autarky can be achieved.



a) b)

Figure 9: a) Grade of self-consumption of the PV energy and b) Annual feed-in energy as a function of the battery size with annual PV generation as parameter. The data is scaled to an annual consumption of 1000 kWh.

5. Combined mode operation

5.1. Simple operation modes

As mentioned, the storage used for the optimization of the self-consumption has no benefit for the grid, if operated without further constraints. Therefore, a combination of the two operation modes would be recommended. Then, the operator has the benefit of the improving the self-consumption of the PV system and the grid operator benefits from reduced impact on the grid.

With the constraint of feed-in limitation two simple, but opposite modes of operation are possible:

1) *Prioritization of autarky*: Keep the charging state of the battery as high as possible, such that as much as possible battery energy is available in case of lack of PV power. However, if the battery is full and still the PV system generates high power, the power must be cut-off in order to limit the feed-in to the grid (compare Figure 5). Then energy gets lost.
2) *Prioritization of feed-in*: Keep the charging state of the battery as low as possible and feed-in as soon as possible to be able to store cut-off energy. However, if the battery is empty and power is needed, it must be purchased from the grid. Therefore this mode lowers the grade of autarky.

Both modes are not optimal and include a financial loss compared to the “pure” operation modes.

For both modes a simulation software was programed, similar to the approach described in the previous chapters. For the simulations the same measured PV data set [6] and as load profile the “Real Home” profile as described in the previous chapter were used. Results for a PV size of 1 kWpk are shown as gray curves in Figure 10. It is clearly visible that with these simple operation strategies only one parameter can be optimized. Either autarky or cut-off energy can be optimized. Both is not satisfying. Therefore, smarter modes of operation are investigated in the following chapter.

5.2. Smart mode of operation

Smart modes of operation aim to optimize autarky and feed-in simultaneously. To obtain this, there is only one degree of freedom: The amount of discharge during night. Any other operation is determined by other needs. This requires a smart control. However, this raises the question: How “smart” is necessary?

This is discussed based on the results of this chapter.

5.2.1. Major operation modes

Two major smart operation modes are possible.

The first smart operation mode puts emphasis on autarky, but considers feed-in. In this mode, the storage is kept as full possible, but storage space for the next day's PV generation is provided by some discharge to the grid. This mode requires an estimate of the excess PV generation of the next day. This way, autarky remains more probable, but if the estimation is not good, energy may be lost, if there is not enough storage space.

The opposite smart operation mode puts emphasis on feed-in, but considers autarky. In this mode the storage is depleted as much as possible, but next day's consumption is left in the storage. This mode requires an estimate of the consumption of the next day. This way, loss of energy becomes less probable, but the grade of autarky may decrease, if there is not enough energy in the storage due to a weak prediction.

The first mode, which puts emphasis on autarky, is presented more in detail, because it is assumed to be more relevant for most of the storage operators.

5.2.2. Prediction methods

Several methods can be applied for the prediction of the next day's consumption or PV generation. Here, the following methods are applied:

- *Omniscient observer*: The available data is used for the prediction as reference.
- *No load*: The load consumption is set to zero. Only the PV generation is considered.
- *Standard load*: The standard load profile for homes (Eon H0) is used for the prediction of consumption
- *Avg. load*: The average of the last 7 days is used for the prediction of the consumption.
- *¼h Avg. load*: Each point of time of the next day is calculated from the average of all points at the same daytime of the last 7 days.
- *Standard PV*: A standard PV profile [4] is used for the prediction of the consumption
- *Avg. load*: The average of the last 7 days is used for the prediction of the PV generation.

Further prediction methods could be weather forecast for the PV generation or a learning observer for the consumption, but are not considered so far.

5.2.3. Simulation and results

The simulation software described in the previous chapter was extended to the smart operation modes. The results are presented in Figure 10a and b. They show as figure of merits (FoM) the parameters grade of autarky and loss of energy as functions of the battery size. The latter corresponds to energy, which needs to be cut due to the feed-in limit. The different colors relate to different operation modes of the storage. The figures are calculated for an annual consumption of 1000 kWh/a and an annual PV generation of 1000 kWh/a with a feed-in limit of 30%. The PV system generates as much energy as needed, but some fraction gets lost as battery losses.

The gray curves show the "dumb" modes of operation. The dark gray curve shows the mode prioritization on autarky, without consideration of feed-in. This gives the best autarky, especially for small storage sizes. But even for large storages a significant amount of energy is cut-off. Contrary, the light gray curve relates to the mode prioritization on feed-in. Here, no energy gets lost with a sufficient large storage, but the grade of autarky doesn't exceed 40%.

The colored curves show the smart operation with emphasis on autarky, but consideration of feed-in. The red curve relates to a perfect prediction due to the omniscient ("all knowing") observer. This is the reference for real prediction methods. The curve for the loss of energy is exactly like in the "dumb" modes with prioritization on feed-in (therefore not visible). The curve for the autarky shows some degrading at medium sized storages up to 4 kWh. Apparently, it seems not possible to optimize both FoM at the same time for this storage size. However, for storages above 4 kWh, the omniscient observer achieves the best values of both FoM.

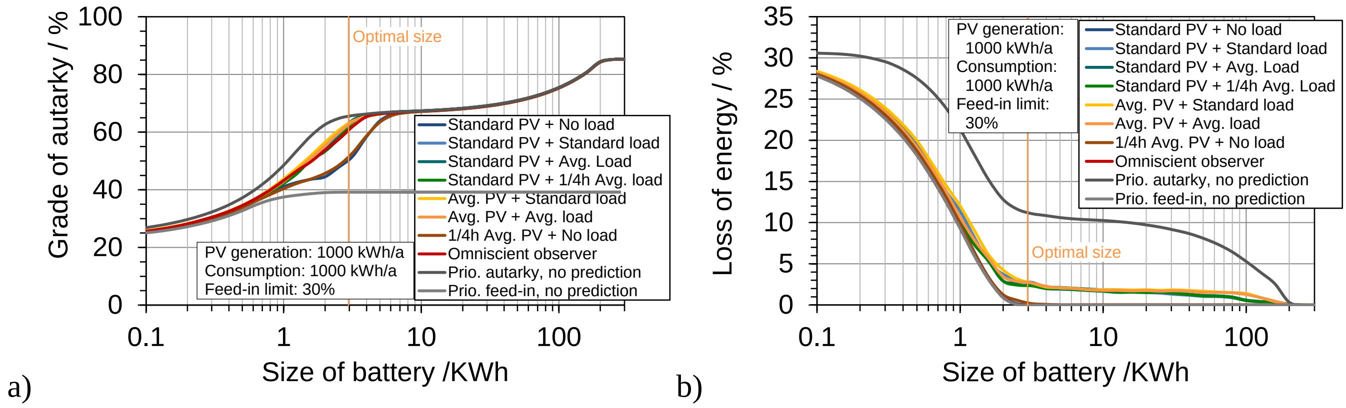


Figure 10: a) Grade of autarky and b) lost cut-off energy as a function of the battery size for smart combined operation of self-consumption with feed-in limitation.
Parameters: PV generation: 1000kWh/a, Annual consumption: 1000kWh/a

The real prediction methods all result in different compromises at small and medium battery sizes. For larger storage sizes, both, autarky and feed-in, can achieve optimal values at the same time. These two are the ones with an assumption of no load for the next day. Therefore, more excess PV energy is assumed and the storage is depleted accordingly. More energy can be stored, such that less is lost. However, for medium sized storages this means, less energy might be available for the self-consumption at the next day. Therefore, the grade of autarky reduces. If the load is considered in any way, the grade of autarky improves, but some 2% to 3% energy is cut-off. Apparently, the prediction method of the load and the PV generation has only little influence on the results, as long as any one is used.

An optimal battery size of about 3 kWh to optimize self-consumption of 1000 kWh/a (see also chapter 4.3) is also an optimal size to optimize feed-in (see also chapter 3.2). To operate the storage in combined mode operation, smart prediction methods, which take the next day's consumption into account, should be considered. Then, the grade of autarky is optimized. Only 3% of the annual energy must be cut-off.

This result can be achieved with a rather simple "smart" algorithm, which doesn't need large effort. E.g. simply averaging the past consumption and PV generation already gives these results. A more precise prediction could even avoid this remaining cut-off of 3%, as can be seen by the values for the omniscient observer. However, this would e.g. include weather forecast or other large effort. It is questionable, whether this effort is necessary to achieve such a comparable small improvement.

6. Conclusions

Especially in rural and suburb areas of Germany, the full PV potential cannot be used due to constraints in the distribution grid. Decentralized batteries in combination with PV systems reduce the load on the distribution grid and allow using more of the PV potential, if combined with a feed-in limitation. The

optimal battery size for such a system scales with the size of the PV system. A daily storage with a size of approximately 3 kWh battery capacity per 1 kWpk installed PV power could be identified as optimum.
A further motivation is the use of the battery to optimize self-consumption of PV-energy and the grade of autarky. Full autarky can only be achieved with a huge seasonal storage or an oversized PV system capable of delivering enough power in winter. An optimum storage size is a daily storage, which scales with the consumption, but not with the PV size. A capacity of about 2 to 3 kWh per 1000 kWh/a annual consumption, independent of the load profile, was found as optimum.
The battery operation for the optimization of self-consumption does in most cases not reduce the peak load on the grid. Therefore, both presented operation modes should be combined. Since both modes require opposite control strategies, a smart operation of the storage is required. It is recommended to discharge the battery in the night by the amount of energy generated in excess during the next day. To predict this amount, a simple averaging of the past consumption and PV generation is sufficient.

7. Acknowledgements

Thanks to Michael Brod for providing the solar data. Michael Roskosch programmed the software for the self-consumption as part of his bachelor thesis [11]. Florian Eck has participated deriving the smart charging algorithms, programmed the related software and provided a lot of figures.

8. References

[1] Jörg Scheffler, "Bestimmung der maximal zulässigen Netzanschlussleistung photovoltaischer Energiewandlungsanlagen in Wohnsiedlungsgebieten", Dissertation, Technische Universität Chemnitz, 18.Juni 2002

[2] Bundesministerium für Raumordnung, Bauwesen und Städtebau, „Wechselwirkungen zwischen der Siedlungsstruktur und Wärmeversorgungssystemen“, Schriftenreihe „Raumordnung“ Band 06.044, Bonn, 1980.

[3] EoN Mitte, Standard Lastprofile (nach BDEW), Jan 2012: http://www.eon-mitte.com/index.php?parent=8847

[4] EnBW Lastprofile, Jan 2012: http://www.enbw.com/content/de/netznutzer/stromverteilnetz/netznutzung/lastprofile/index.jsp

[5] KFW-Förderprogramm „Erneuerbare Energien – Speicher“, Website, 15.9.2013: https://www.kfw.de/inlandsfoerderung/%C3%96ffentliche-Einrichtungen/Kommunale-Energieversorgung/F%C3%B6rderprodukte/Erneuerbare-Energien-%E2%80%93-Speicher-(275)/#1

[6] Private communication of the measurement data of the PV system of Michael Brod, Kronberg, Taunus, Feb. 2012, for the time between 1.1.2012 to 31.12.2011.
System data: Rated power: 4.51 kWpk, roof slope: 30°, direction: 40° to west. Time resolution of the data set: 15 min.

[7] „Erzeugungsanlagen am Niederspannungsnetz – Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Niederspannungsnetz“, VDE Anwendungsregel VDE-AR-N 4105, Aug. 2011, verbindlich gültig ab 1.1.2012.

[8] Wolf von Fabeck,
“Versorgung einer Industrienation mit Erneuerbaren Energien erfordert Speicher“,
Solarzeitalter 3/2012, Oct. 2012, p. 69

[9] Website of NEPLAN, 15.Aug. 2012: http://www.neplan.ch/

[10] Eberhard Waffenschmidt,
“ Solarstromeinspeisung in Niederspannungsnetzen“,
Solarzeitalter 1/2013, Apr. 2013, p. 44

[11] Michael Roskosch,
"Optimierung des Eigenverbrauchs von Photovoltaikanlagen mit Speicher",
Bachelor thesis at Cologne University of Applied Science, faculty of Information, Media and Electrical Technologies, Cologne, 2.Aug.2013.