Hybrid Provision of Energy based on Reliability and Resiliency by Integration of Dc Equipment

Work Package WP3

Hybrid Grid enabling Solutions

Deliverable D3.2

Component Sizing Tool

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List of Abbreviations

AC	Alternating Current
ACDC	Alternating Current and Direct Current
AIT	Austrian Institute of Technology
BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CSV	Comma Separated Values
DC	Direct Current
DER	Decentralized Energy Resources
DoD	Depth of Discharge
FiT	Feed in Tariff
HTML	Hypertext Markup Language
LCOE	Levelized Cost of Electricity
LFP	Lithium iron phosphate
LVAC	Low Voltage Alternating Current
MVAC	Medium Voltage Alternating Current
NPV	Net Present Value
OPEX	Operational Expenditure
PCC	Point of Common Coupling
PV	Photovoltaics
RES	Renewable Energy Sources
SoC	State of Charge
SoH	State of Health
WP	Work Package

Executive Summary

The Component Sizing Tool is an online tool, which can be used for the sizing of system components used within Alternating Current (AC), Direct Current (DC) and hybrid Alternating Current and Direct Current (ACDC) networks. The Deliverable of the Component sizing Tool is an online Component Sizing Tool, with an additional report explaining the calculations and simulations in the background. The simulation model and the online tool, however, remain the intellectual property of Austrian Institute of Technology (AIT), the code itself will not be made public. The component sizing tool for technical and economic optimization within the HYPERRIDE project is lead by AIT who is responsible for the tool development and implementation, in colloaboration with additional partners EMOTION and ASM, whos role are to provide the neccessary profile data for the simulations.

The component sizing tool for economic optimisation will provide a technical and economic base for finding the optimal component size solution for three different use cases within the HYPERRIDE project. The first use case is as an addition to the Grid Planning Tool for the development of Hybrid ACDC microgrids, for the simplified simulation of battery storages within Hybrid ACDC micro grids. Secondly, the tool will be used for simulations in the Italian pilot as EMOTION and ASM are the main contributors. Therefore, input data from the partners will be pre-implemented into the online tool to simplify the tool usage. As a third use case, the tool will be used to generate input parameters for creating business models, regulatory assessment and identify consumers.

The online Component Sizing Tool is currently available under http://sizing-tool.hyperride.eu.

1 Introduction

1.1 Purpose and Scope of the Document

The purpose of this Task was to develop a Component Sizing Tool which can be used for the sizing of different ACDC and DC system components, such as generation units, converter sizes and, if available, BESS sizes. Therefore, an existing online simulation tool, which was developed by AIT in the years 2019 and 2020 was reused and adapted according to the HYPERRIDE requirements. The adaptations to the original work included further enhancements of the online interface and thereby improving the tool usability. Additional improvements also facilitated increased tool performance and adaptations specifically required for HYPERRIDE such that it could be implemented for in ACDC and DC system applications

In HYPERRIDE the Component Sizing Tool shall be used in addition to the Grid Planning Tool for the development of hybrid ACDC microgrids for BESS simulations, which is developed within another Work Package (WP). In the Italian pilot, the Component Sizing Tool shall be used for configuring the system component sizes. Further, the Component Sizing Tool will provide a technical and economic baseline for finding the optimal component sizes in order to propose a solution for the different use cases and business models.

1.2 Structure of the Document

This document is organised as follows: Section 1 provides information about the report content. Section 2 provides a more detailed overview on the Component Sizing Tool itself, thereafter Section 3 describes the Component Sizing Tool components and required input data and parameters. Section 4 provides an overview of the tool output reports and describes the manner for the results can be interpreted. Lastly, Section 5 offers an outlook to the further usage of the Component Sizing Tool within HYPERRIDE while Section 6 the deliverable and concludes the next steps towards future developments and enhancements.

2 Component Sizing Tool Introduction

The Component Sizing Tool is a steady state simulation which can be used for configuring behind the meter system components. This includes the generation unit, the BESS and AC/DC and/or DC/DC converters connected to either the generation unit or the BESS. However, the Tool itself does not provide an optimization function, meaning that the Component Sizing Tool displays the necessary data for component sizing, however, the sizing itself has to be done by the user.

The simulation itself is based on a generation and/ or consumption units, converters, BESS and, if available, a grid connection point. Furthermore, the Component Sizing Tool is coupled with an operation strategy. For the purpose of the defined use cases, the operation strategy is used for increasing self-consumption, meaning that the main incentive of the BESS is to feed the least amount of energy produced by Renewable Energy Sources (RES) into the grid. Based on the BESS operation, the Component Sizing Tool calculates a charging power profile, the residual load profile and actual power profile at the grid connection point. Based on these power profiles, as well as Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) cost calculations, the Component Sizing Tool further calculates the economic system viability over the simulated time horizon. As mentioned, the Component Sizing Tool is a steady-state simulation, not an optimisation. However, it can be used for creating and evaluating parameter dimension and system mode operations assessments, and therefore, based on the techno-economic evaluations, for sizing the individual components. The evaluation of assessing the optimal solution, however, as mentioned above, has to be done by the user.

The Component Sizing Tool is developed in Python 3.7, while the online Tool (with a Dashboard user interface) is based on Dash by Plotly (Python, n.d.), (Plotly, n.d.).

2.1 Developments within HYPERRIDE

The core functionalities of the Component Sizing Tool were developed within AIT over the last years. The system components and interconnections can be seen in fig. 1. The code was mainly used for customer projects and necessary functionalities were developed step by step based on customer use cases. Further existing was a similar online tool to the Component Sizing Tool. The core focus however was not component sizing but mainly battery sizing and evaluating different behind the meter battery use cases in solely AC grids. Part of the original code was a battery that was directly linked to an ACDC converter, with one set efficiency curve. The consumption and generation power profiles were expected to be actual AC power profiles. Also pre-existing were two operation strategies, the self-consumption strategy, which was further utilized in HYPERRIDE and the peak shaving operation which was not included in the Component Sizing Tool due to remaining performance issues.

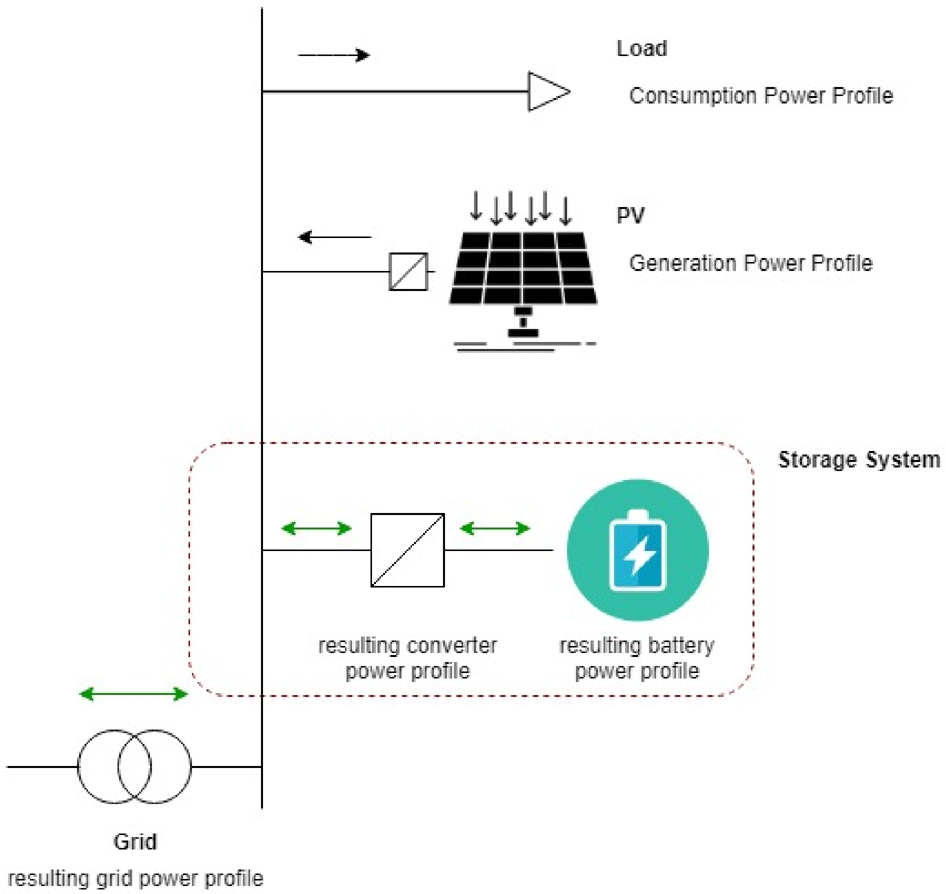

Figure 1: System Components of the AIT BESS sizing tool, before further developments in HYPERRIDE.

During the HYPERRIDE project, the already developed code was restructured and partly rewritten, such that the results were independent code components that can be linked to any specific use case. In order to separate the system components, the battery was separated from the ACDC converter. Further, the ACDC converter exchanged by a converter which can be defined by the user. The user now can define the converter by setting the overall conversion efficiency between 90 and 99 %. The generation profile was first expected to be an AC power profile and therefore already including conversion losses. Within HYPERRIDE this expectation was resolved by adding a converter to the generation unit which can also be defined by the user. However, if the conversion is included in the power profile, the user can set the converter efficiency to "Converter is included in profile" which will set the conversion factor to 100 %.

The new tool structure can be seen in fig. 2. The orange converters were specifically added for the ACDC hybrid grid. Before, the system solely included the converter which is directly connected to the storage system. Anyhow, the load profile is expected to already include the conversion losses, as the load might consist of multiple consumers with different conversion factors. The resulting power profile at the Point of Common Coupling (PCC), before the Medium Voltage Alternating Current (MVAC)/Low Voltage Alternating Current (LVAC) transformer, does not yet include the DC/AC conversion.

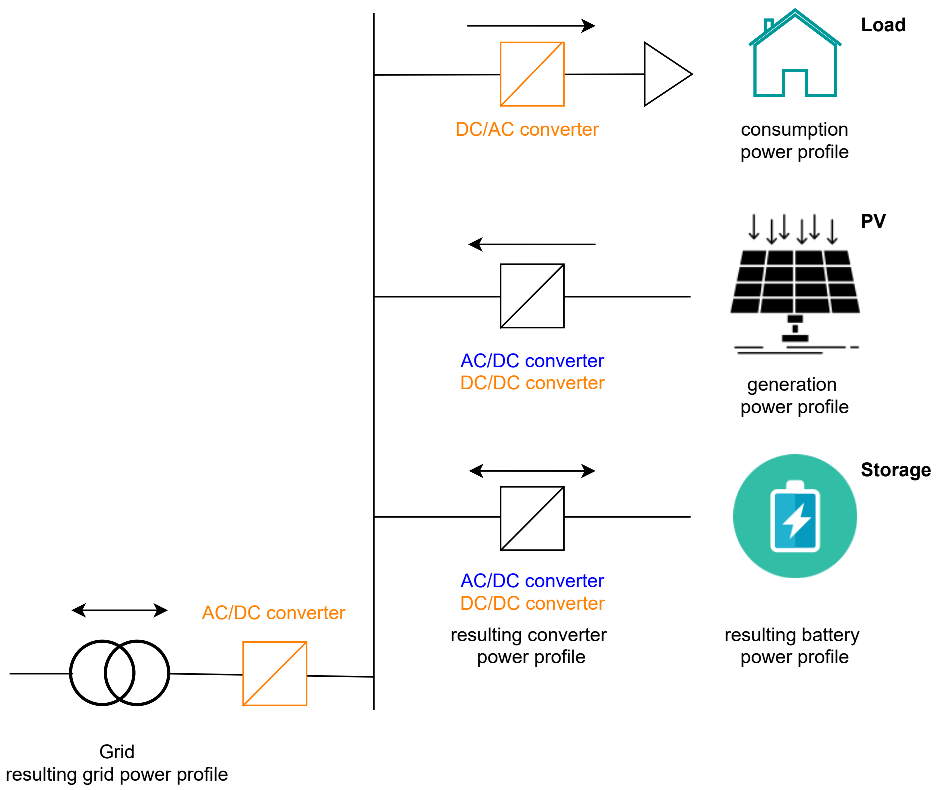

Figure 2: System Components of the Component Sizing Tool, as developed in HYPERRIDE.

Additionally, within HYPERRIDE the existing online tool was adapted, extended and enhanced to the now called Component Sizing Tool. Therefore the online tool was completely re-written based on the new system components and adding the possibility to simulate AC grids as well as DC grids and ACDC hybrid grids. The original online Tool had one pre-defined profile each for the consumption and the generation unit. The Component Sizing Tool now has three pre-defined load profiles, a residential load profile for a family of four, an office building with 100 employees and the power profile of the Italian pilot. The available generation profiles include four profiles generated by PVGis with the location in Vienna, facing south, east, west and east-west. Further, a fifth generation profile, for the Italian pilot, was implemented. Further, the possibility was added to directly access the API of PVGis and directly download any PV generation profile for any location, azimuth and tilt (Huld, Müller, & Gambardella, 2012). Additionally, the user has the opportunity to upload independent power profiles which are not stored within the Component Sizing Tool. The now available Component Sizing Tool can simulate up to five system configurations at once. The installed nominal PV power, the PV converter, the BESS and the BESS converter can be defined independently for each system configuration. This enables the user to evaluate and compare system configurations with different generation power plants and/or equal system configurations in AC grids with AC/DC hybrid grids. An example of that can be seen in Section 5.

Concluding, many core functionalities were pre-existing but were adapted and enhanced during HYPERRIDE. The applicability of the Component Sizing Tool for AC/DC hybrid grid was added, and the online Component Sizing Tool was created based on pre-existing code elements and newly created and/ or adaped code elements.

3 Tool Component Description and Input Data

The Component Sizing Tool consists of multiple components which are integrated in order to create an overall system. Figure 3 shows the core storage simulation model in blocks (within the red dotted line) and the respective component interactions. Furthermore, the necessary in- and output profiles required and generated by the core storage simulation model are shown.

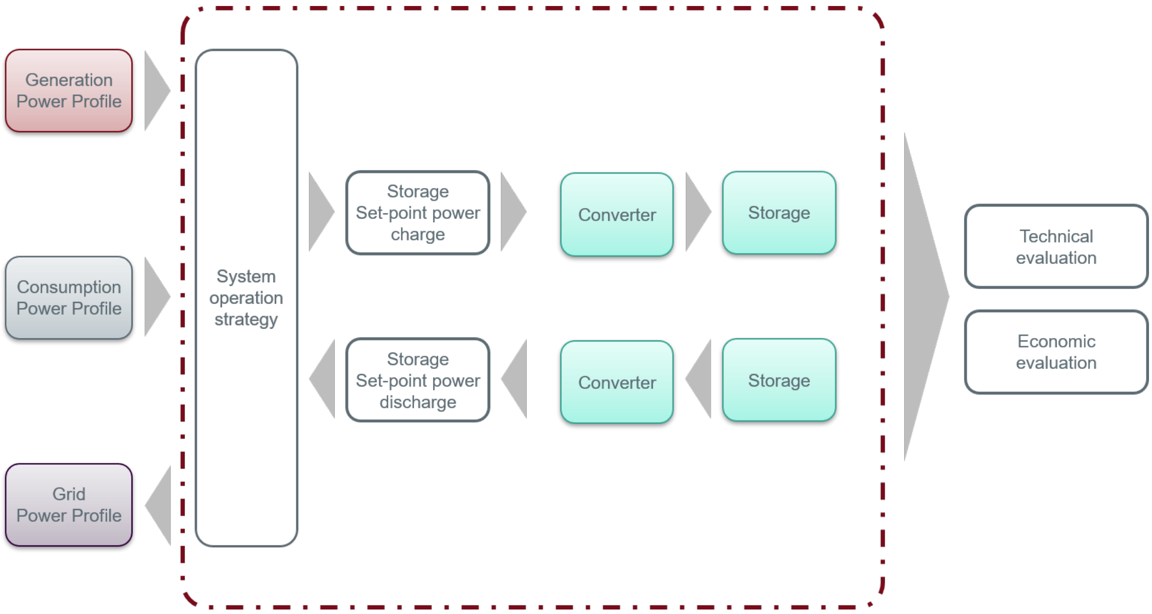

Figure 3: Schematic Component Sizing Tool components and component interaction.

The model behind the online tool is implemented in Python 3.7 and is separated into four main parts, shown in Figure 4. (Python, n.d.)

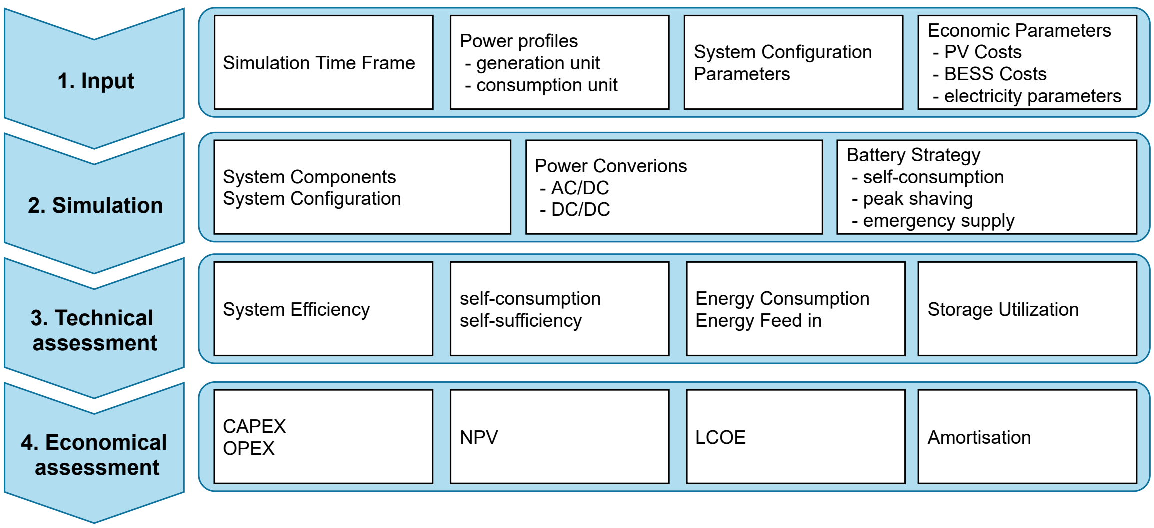

Figure 4: Simulation workflow.

1. Input: The first part "Input" includes the uploading and scaling of the load and generation profiles, the gathering of all the relevant simulation parameters. The simulation parameters are used for defining the core storage system, within the red dotted line in Figure 3. Based on the

configured simulation parameters the BESS size, lifetime, converter power, converter efficiency and the battery system operation strategy are defined. The consumption and generation profile input, are scaled and further used as input to the system operation strategy.

2. Simulation: The second main part is the core storage system itself. As part of the "Simulation" process, the system operation strategy block defines the converter and storage set-point power based on the system operation. The set-point power values are forwarded first to the converter, then to the battery. The set-point power values are evaluated, assessed and, if necessary, limited to fit each component, based on nominal power and or available capacity. The BESS is finally charged or discharged with the resulting converter and storage operation power. In return, the system operation strategy block receives and monitors the limited converter and storage operation power and other component operation values.

3. Technical Assessment: The third part, the technical assessment is based on the received values from the system operation strategy block. The technical assessment includes battery status evaluations such as charging power, State of Health (SoH), State of Charge (SoC) and efficiency. Further, it is used to validate the technical benefit of each storage application by the amount of energy fed into the grid, the remaining grid consumption, the self-sufficiency rate and the self-consumption rate.

4. Economical Assessment: The fourth part, the economical assessment is based on the technical evaluation and includes costs such as electricity costs, component investment and operation costs. Based on these values the economic assessment is executed, concluding the techno-economic evaluation. The techno-economic evaluation can finally be used for optimising the system component sizes.

The following subsections will provide a short overview of the different components, the component implementation, the predefined profiles and data sources.

3.1 System Operation Strategy

The system operation strategy in the Component Sizing Tool is defined for self-consumption optimisation. Meaning, that energy generated on-site should be used directly on-site. Energy generation which cannot be used directly by the simultaneous on-site consumption should be stored in the BESS. Only in the case when the BESS is fully charged, the generation shall be fed into the grid. In case the generation is lower than the simultaneous on-site consumption the BESS shall be discharged until it reaches the Depth of Discharge (DoD). Only when the BESS is fully discharged, the on-site consumption shall be covered by grid usage.

Another system operation strategy, peak shaving, was considered to be further implemented in the Component Sizing Tool. When utilizing the battery storage in peak shaving operation, the power at the PCC is smoothed and thereby the maximum power is reduced. By reducing the maximum power at the PCC, it is possible to implement smaller converters and transformers at the PCC, which leads to a reduction in investment costs. The implementation of the peak shaving operation strategy would have been possible. However, as the peak shaving system operation strategy is based on an optimizer model, the simulation performance is reduced, leading to a simulation duration that was considered to be non-user-friendly. Therefore, peak shaving operation was not implemented in the tool. However, if it proves to be necessary to use peak shaving operation AIT offers to run simulations specifically for the needed use case.

3.2 Converter Model

The converter model can be considered to be the main interconnection point to the use cases and pilot projects within the HYPERRIDE project. As also shown in Figure 5, there are two main conversions considered. Firstly, the conversion from the generation power plant (in this case a PV power plant) to the grid and secondly the conversion from the grid to the battery storage. In an ACDC grid, this would mean a conversion from the PV output in DC to AC and conversion from AC to DC in order to store the generation within the storage, plus DC/DC conversions within the PV system and the battery storage.

Users can choose the overall system conversion efficiency of both conversions and thereby differentiate between ACDC and DC grids converters without having specific products defined. Efficiencies can be chosen between 90 to 99 % in 1 % steps. The efficiency curves were extracted from PowerFactory (*PowerFactory*, 2019). If the power conversion of the generation power plant is already considered in the generation profile, instead of choosing an efficiency, the user can enter that the conversion is already considered. An example of the converter efficiency curve for an efficiency of 97 % can be seen in Figure 5.

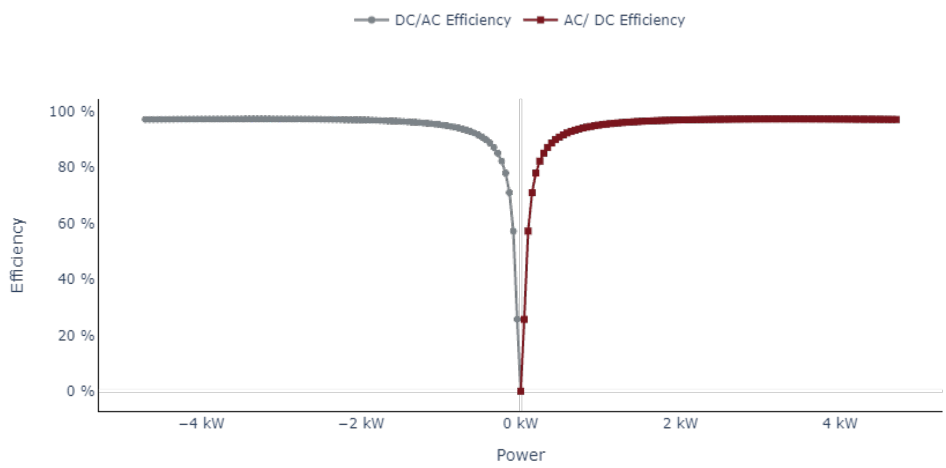

Figure 5: Converter Efficiency at 97 %.

By sizing the converter as close to the required power the operation time in partial load can be minimised. As the efficiency in partial load, as can be seen in Figure 5, is much lower than at nominal power, the system efficiency can be increased when choosing the smallest possible converter parameters.

3.3 BESS Model

The battery model is another core part of the component sizing tool. It is based on a Lithium iron phosphate (LFP) battery. The battery is built upon a nominal power, capacity, depth of discharge, efficiency, and battery ageing process.

3.3.1 BESS capacity

As can be seen in Figure 6, the battery capacity can be differentiated into actual and usable capacity.

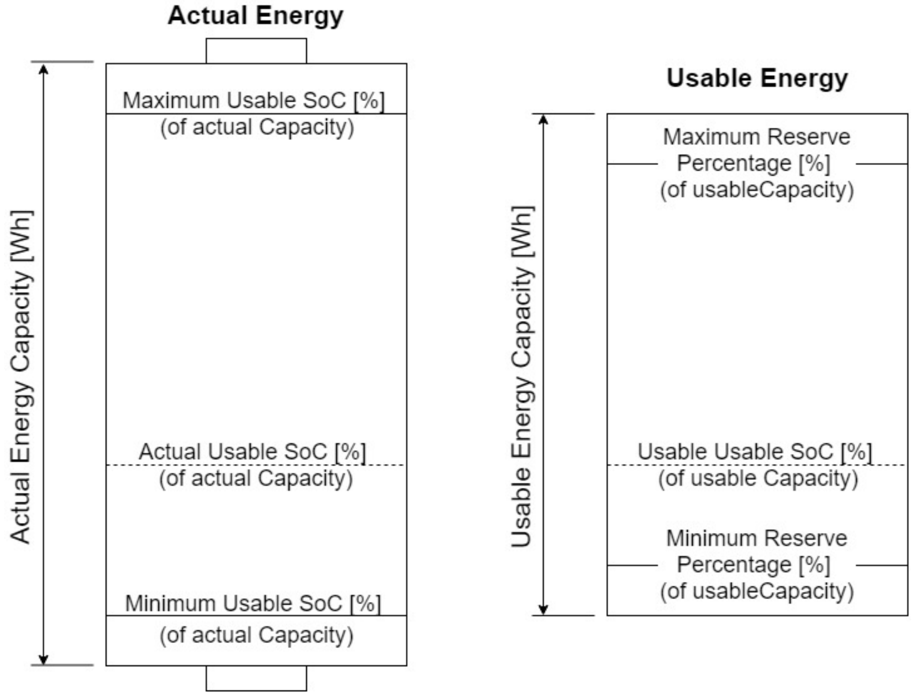

Figure 6: Visualisation of actual and usable BESS energy capacity (Kapeller, 2020).

Available capacity is the total amount of energy (Wh) the storage system can chemically store. The usable capacity defines the amount of watt-hours that can be used based on the chemical system design and SoH. Within the Component Sizing Tool the battery is installed with a starting SoH of 100 % and exchanged at an SoH of 80 %. In literature, instead of referring to the usable capacity, the term DoD can be found. The DoD is the counterpart to the usable capacity and defines, what percentage of the battery capacity shall not be used, either because it would fall below the minimum SoC, or it would exceed the maximum SoC. In the case of LFP batteries, the usable capacity is set to 80 % of the actual capacity. The DoD in this case therefore would be 20 %.

As an example, a BESS at an SoH of 100 % and an actual capacity of 1 kWh with a minimum usable SoC of 10 % and a maximum usable SoC of 90 % translates to 0.8 kWh usable capacity. The usable capacity is bound to the number of Watt-hours related to the percentage of actual capacity, meaning 0.2 kWh are reserved for minimum and maximum usable SoC. Due to BESS degradation, the actual energy within the BESS reduces, which consequently reduces the usable energy capacity. At a BESS degradation to 80 % SoH, the 0.2 kWh reserved capacity for minimum usable SoC and maximum usable SoC remains constant, while the usable capacity is reduced to 80 %, leading to a remaining usable capacity of 0.6 kWh.

3.3.2 BESS ageing process

The battery ageing process (cf. Equation (1) and Equation (2)), defining the SoH, consists of two independent ageing processes, the calendar ageing and the cyclic ageing process. Cyclic ageing is considered to be a linear process, based on a cycle life of 5000 cycles.

$$A_{cycle}(t) = \frac{n_{cycles}}{\text{cycle life}} \tag{1}$$

$A_{cycle}(t)$ ... battery cyclic ageing after n_{cycles}
n_{cycles} ... amount of battery full charging cycles
cycle life ... amount of expected battery full charging cycles until the battery reaches a SoH of 80 %, as defined by the manufacturer

The calendar ageing is based on the Arrhenius law (Popp, 2014). The Arrhenius law describes the ageing process of one time-step, based on the SoC and battery temperature.

$$A_{calendar}(t) = A_0 * e^{\frac{T_B - T_0}{b}} * e^{\frac{soc - soc_0}{c}} * \sqrt{t} \tag{2}$$

$A_{calender}$ ... battery ageing after t seconds
A_0 ... absolute ageing factor at reference conditions
T_b ... actual battery temperature
T_0 ... battery temperature at reference condition
SoC ... actual battery SoC
SoC_0 ... SoC at reference condition
t ... ageing time

3.4 Grid Connection Point

The grid connection point is the resulting power profile of the power profile inputs and storage operation. In other words, energy generation which is not directly used, and cannot be stored has to be fed into the grid. Energy consumption which can neither be directly covered by Decentralized Energy Resources (DER), nor by the installed storage system is withdrawn from the grid. Following, the resulting grid power profile can be used for technical assessments such as necessary grid connection power, grid usage and time of usage, self-sufficiency and self-consumption.

The resulting grid power profile can further be used for the economic evaluations such as, calculating electricity costs per year as well as annual revenue based on Feed in Tariff (FiT).

3.5 Economic Calculation

The economic calculation follows the technical simulation. Therefore, the user can enter different economic parameters for the system components. For the PV generation system, parameters such as CAPEX (for the plant and converter), as well OPEX can be defined. Further, the user can define CAPEX and OPEX for the battery and battery converter. At last, the user can define electricity costs and FiT. Based on the economic parameters the overall system CAPEX and OPEX are calculated as the sum of all partial CAPEX (cf. Equation (3)) and OPEX (cf. Equation (4)) components. Further calculated are the Levelized Cost of Electricity (LCOE) and Net Present Value (NPV). Both, the LCOE (cf. Equation (9)) and NPV (cf. Equation (8)) are calculated under consideration of the remaining value of the system components at the end of the simulated time frame. The remaining value of the BESS is based on the SoH, the remaining value of the PV power plant is based on an estimated lifetime of 15 years. Based on the LCOE and NPV, the user can finally further size system components based on the economic revenue

$$CAPEX = \sum((CAPEX_{PV} + CAPEX_{\text{PV converter}} + CAPEX_{BESS} + CAPEX_{\text{BESS converter}}) * \frac{1}{(1+i)^n}) \quad (3)$$

$$OPEX = \sum((OPEX_{PV} + OPEX_{\text{PV converter}} + OPEX_{BESS} + OPEX_{\text{BESS converter}})) * \frac{1}{(1+i)^n} \quad (4)$$

$$revenues = \sum(FiT * E_{feed-in} * \frac{1}{(1+i)^n}) \quad (5)$$

$$\text{remaining value}_{PV} = (CAPEX_{PV} + CAPEX_{\text{PV converter}}) * \frac{PV_{\text{life time}} - t_{end}}{PV_{\text{life time}}} * \frac{1}{(1+i)^(t_{end})} \quad (6)$$

$$\text{remaining value}_{BESS}(t_{end}) = (CAPEX_{BESS} + CAPEX_{\text{BESS converter}}) * \frac{1 - SoH(t_{end})}{1 - SoH_{\text{EoL}}} * \frac{1}{(1+i)^(t_{end})} \quad (7)$$

$$NPV = CAPEX + OPEX + revenues + \text{remaining value}_{PV} + \text{remaining value}_{BESS} \quad (8)$$

$$LCOE = \frac{CAPEX + OPEX + revenues + \text{remaining value}_{BESS}}{\sum(E_{sum} * \frac{1}{(1+i)^n})} \quad (9)$$

$E_{feed-in}$ ... Sum of energy fed into the grid
E_{sum} ... Sum of energy consumption over complete time frame
FiT ... Energy feed in Tariff
i ... interest rate (5 % per year)
n ... number of time periods within simulation time frame
$PV_{\text{life time}}$ ... expected lifetime of the PV power plant (15 years)
SoH ... State of Health
$SoH_{EoL})$ ... State of Health at the end of lifetime of the BESS
$SoH(t_{end})$ ... State of Health at the end of the simulation time frame
t_{end} ... end year of the simulation time frame
t_{start} ... start year of the simulation time frame

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3.6 Profile Data

The consumption, as well as the generation units, are based on power profiles. The power profiles can either be chosen out of a list of predefined profiles, uploaded by the user as a Comma Separated Values (CSV) file or in the case of PV generation downloaded from PVGis directly within the Component Sizing Tool (Huld et al., 2012).

All profiles can be scaled by the user. Generation profiles may be scaled by the amount of installed kW peak. Consumption units can be scaled by yearly consumption.

The power profile time step resolution is not defined by the Component Sizing Tool. In the case of differing profile time step resolutions, the smallest common denominator is evaluated and both profiles are interpolated to match the common resolution. However, in order to ensure sufficient simulation accuracy at a sufficient performance, the profile resolution should have a minimum resolution of 1 min and maximum resolution of 1 h, with an ideal value between 10 and 15 min. To further ensure a sufficient simulation performance, the simulation time interval when using the tool should not exceed 1 year, for simulations over a longer time horizon, AIT will perform the simulations locally to ensure the simulation performance.

3.6.1 Predefined Consumption Units

The predefined profiles are a residential household and an office building.

The residential household profile was generated using the LoadProfileGenerator Version 9.1 developed by Noah Pflugradt (Pflugradt, 2019). The residential household profile represents a household consisting of 2 working adults and 2 children with an annual consumption of 3 140 kWh/a. The office building profile is a standard load profile from APCS scaled to 100 employees and an annual consumption of 192 500 kWh/a, under the assumption of one employee using 1 925 kWh/a. (APCS Power Clearing and Settlement AG, n.d.) (Bayer, Sturm, & Hinterseer, 2011)

Figure 7 shows the list of pre-defined consumption power profiles.

3.6.2 Pre-defined PV Generation Profiles

There are five different PV profiles available. Four PV profiles were extracted from PVGis with 1 kWp, installed for the location of Vienna. The profiles differ between Azimuth and tilt. The PV profiles downloaded from PVGis have a time resolution of 1 h. The original profiles from PVGis range from 2013 to 2016 and were extended until 2040, by repeating the originally extracted four years until 2040. (Huld et al., 2012)

The fifth implemented PV profile was provided by ASM, containing the PV generation data from the Italian pilot site. The PV generation profile has a time resolution of 10 min. The power profile ranges from August 2018 to August 2019.

Figure 8 shows the list of pre-defined PV power profiles.

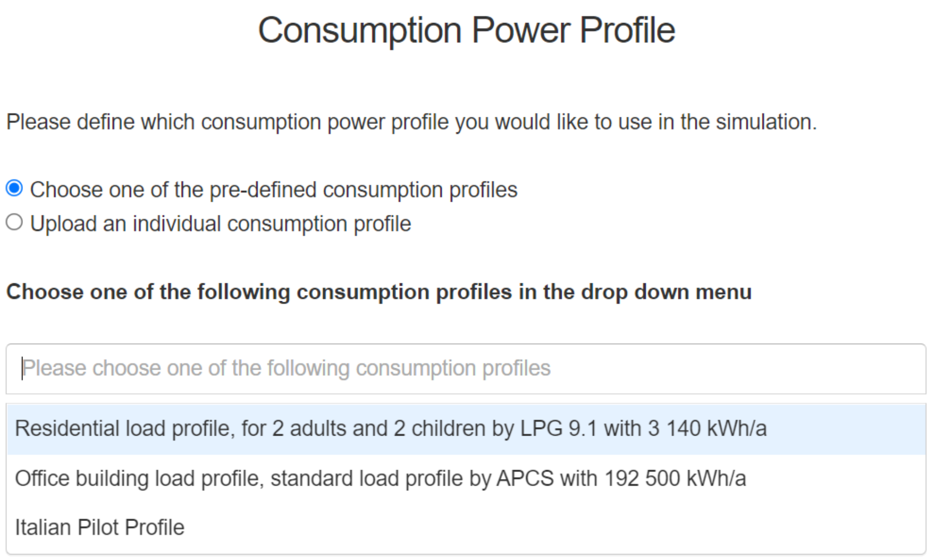

Figure 7: List of pre-defined consumption profiles.

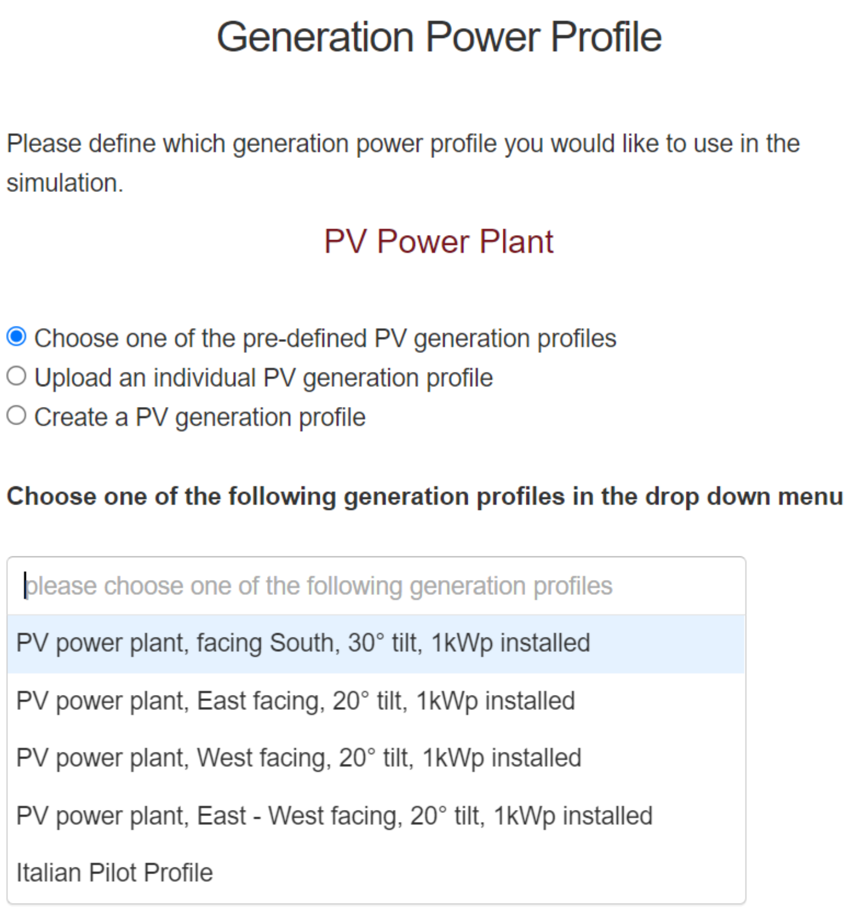

Figure 8: List of pre-defined PV profiles.

3.6.3 Uploading Power Profiles

Uploaded power profiles are not stored in the Component Sizing Tool and therefore have to be uploaded each time the tool is started or reloaded. To upload a profile, the profile has to be a CSV file. Further, the CSV file has to contain a minimum of two columns, a column for date and time and one for the actual power data. The CSV file must not consist of more columns than maximum the index, date, time and generation profile. The exact columns can be specified within the Component Sizing Tool. Further, to upload power profiles the exact CSV format for decimal, column separator and date-time format has to be set. If any of these parameters are incorrect, the tool will not be able to read the file. Further, the CSV data unit has to be entered, these units will be scaled to kWh for further data processing. Figure 9 shows an example of how a power profile can be uploaded by the user.

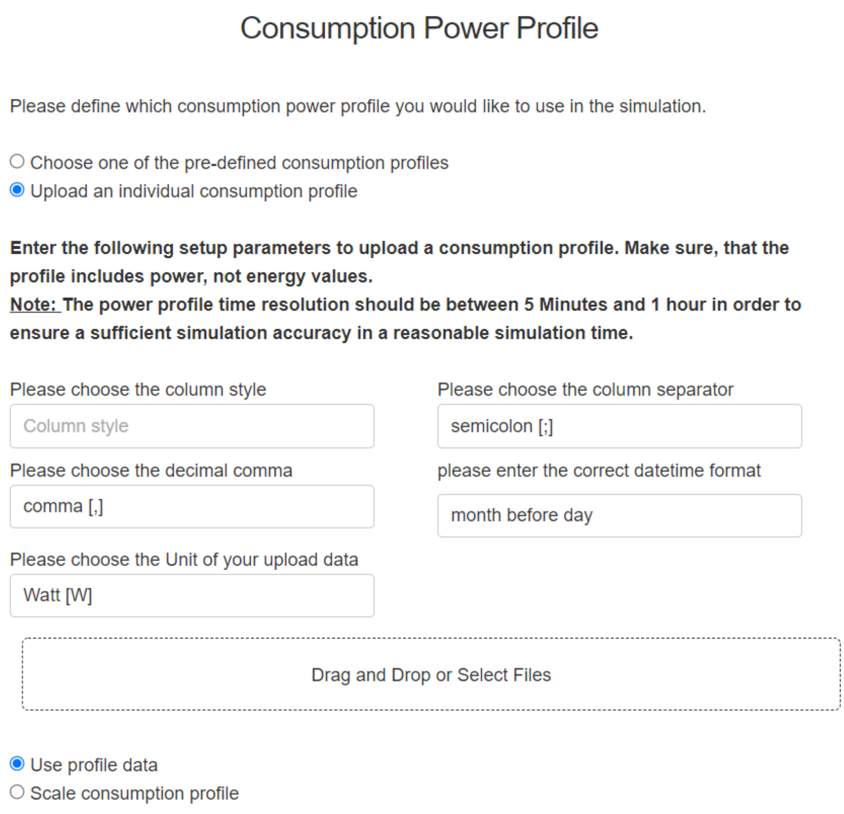

Figure 9: Example of how to upload a consumption profile.

3.6.4 Loading PV Generation Power Profiles from PVGis

Additionally, PV profiles can be extracted directly from PVGis using the Component Sizing Tool. Therefore, the user has to enter the location, the installed PV peak power, the module tilt, azimuth and the type of module mounting directly in the Component Sizing Tool. PVGis offers PV data starting from 2005 until 2016. Figure 10 shows an example of how a PV profile can be downloaded from PVGis.

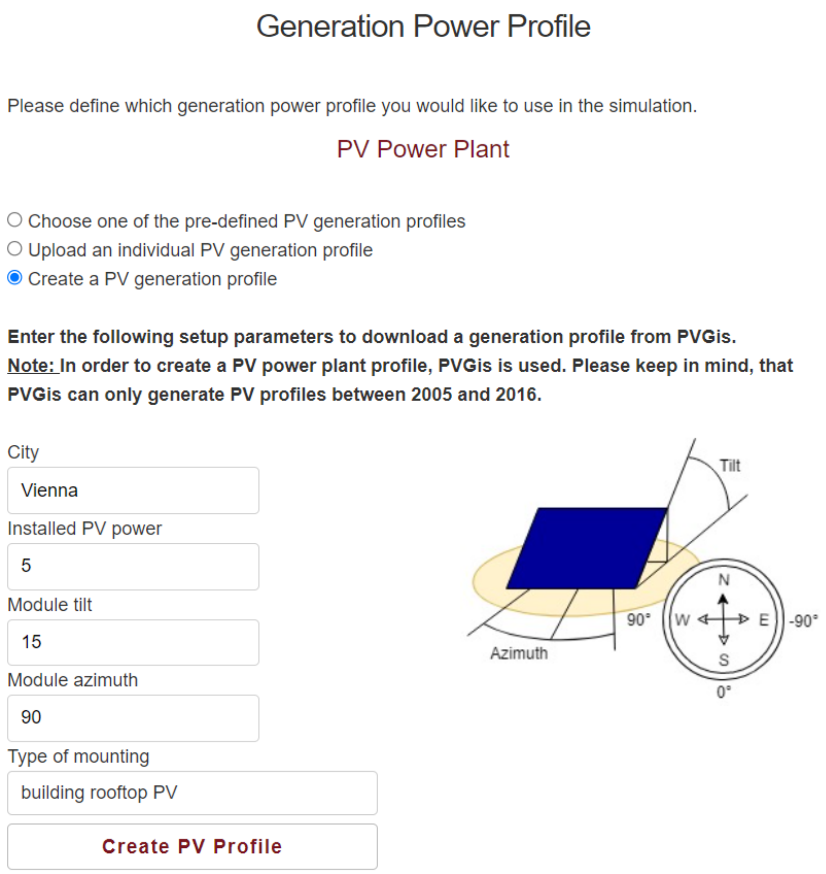

Figure 10: Example of a PV profile download from PVGis.

4 Tool Outputs

The Component Sizing Tool has multiple output reporting files. There are five different Hypertext Markup Language (HTML) files, as well as the specific component operation with values as per the time step. HTML files can be downloaded as HTML, the component operation can be downloaded as a CSV file. These reporting files include the following:

- Consumption Profile Analysis
- Generation Profile Analysis
- Storage Analysis
- Application Analysis
- Economic Analysis

4.1 HTML Evaluations

4.1.1 Profile Analysis

The first and second HTML analysis is the profile analysis, which is used for analysing the generation, as well as the consumption profile. The profile analysis evaluates the profile's energy per month, the power distribution per year, per month, and by daytime. The profile analysis can specifically be used for evaluating the time of power generation and/ or consumption. By comparing the profiles the generation component sizes can be evaluated and optimised to better fit the consumption.

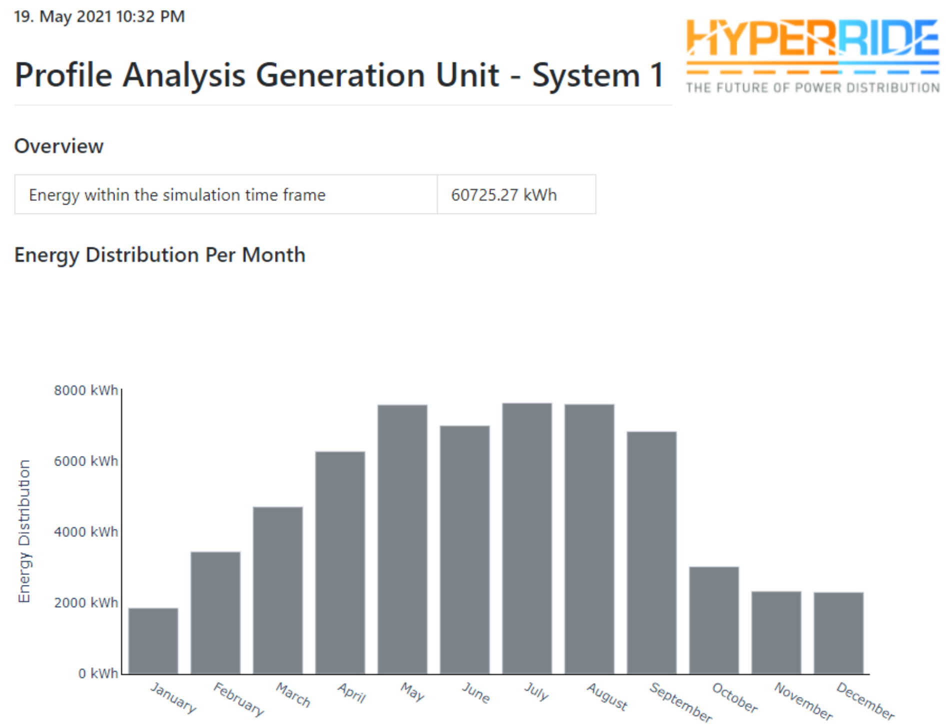

Figure 11: Partial profile analysis of a PV power with 50 kWp installed, facing south with 30 degree tilt.

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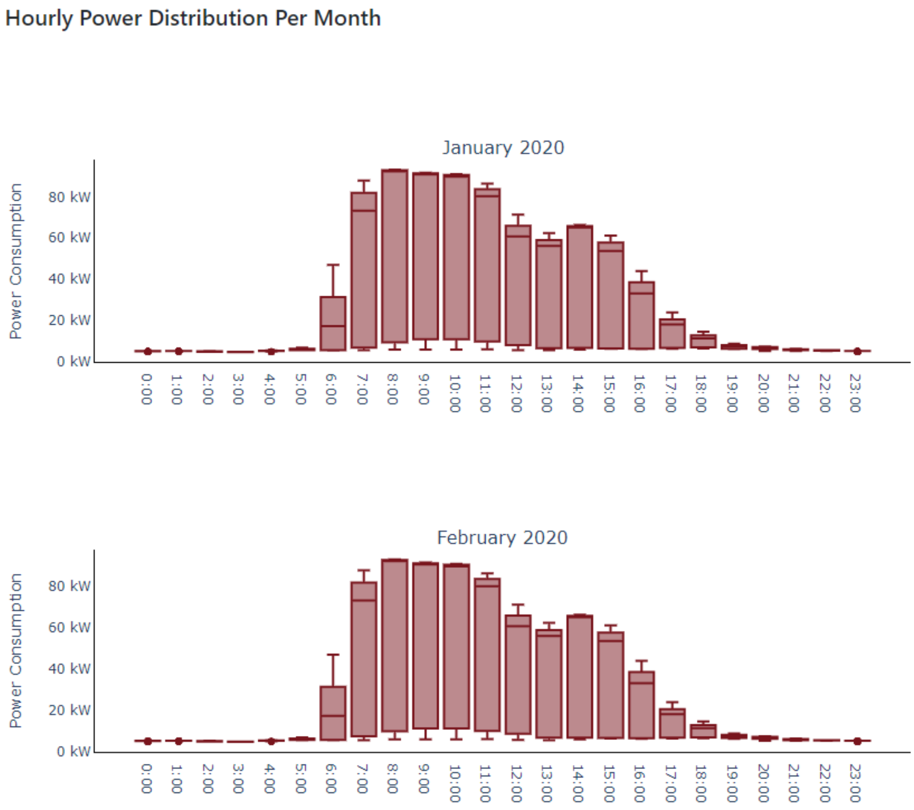

Figure 12: Partial profile analysis of an office building consumption profile with 192 500 kWh/a.

Figure 11 shows parts of the HTML Profile analysis for a PV generation power plant with 50 kWp installed nominal power, facing South with a tilt of 30 degrees. Figure Figure 11 shows, the yearly energy generation as a table as well as the monthly energy generation as a histogram with monthly intervals, showing the typical monthly energy distribution for PV power plants.

Figure 12 shows parts of the profile analysis for a consumption profile. In this case, the profile is a standard load office building profile extracted from APCS and scaled to a yearly load of 192 500 kWh/a. Figure 12 shows the power distribution as boxplots per month and time of day. The figure shows that the power consumption rises in the morning when employees start to arrive at the office building. It further shows a short power decrease during lunch break and a decreasing power consumption in the evening. The power consumption at night times is nearly zero as only the base loads remain. Comparing the power distribution per daytime for PV generation and power consumption, it can be seen, that the PV power plant complements the energy generation of the office building, as the generated energy can directly be used on-site without being stored.

4.1.2 Storage Analysis

The storage analysis is the third HTML analysis. The storage analysis documents the battery parameters, evaluating the storage charging and discharging power, as well as the BESS mean efficiency and efficiency distribution. Further, it graphically evaluates the charging/discharging power and SoC distribution. The storage analysis shows the highest and lowest charging power, by evaluating the power distribution, the nominal storage and converter power can be optimised. By optimising the nominal power, the BESS efficiency is also optimised. Further, by evaluating the SoC distribution the storage capacity can be optimised.

Battery Storage System Operation Statistics

Value	Unit	Min	5%	25%	50%	Average	75%	95%	Max
SoC	%	-0.00	-0.00	0.00	0.00	12.17	0.00	94.65	100.00
Charging Power	kW	0.00	0.00	0.00	0.00	0.68	0.00	1.06	37.69
Discharging Power	kW	-36.10	-4.34	0.00	0.00	-0.56	0.00	0.00	0.00
Charging Efficiency	%	0.16	33.23	87.42	91.84	84.18	93.07	93.28	93.29
Discharging Efficiency	%	0.00	68.25	87.42	88.24	84.95	88.85	90.50	93.29

Power Distribution

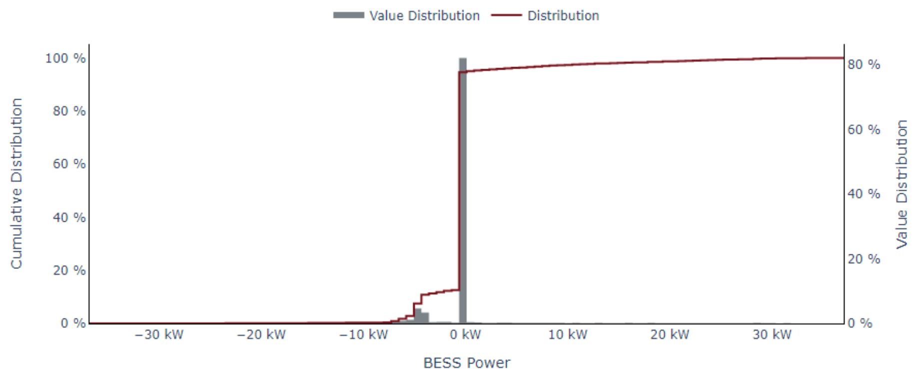

Figure 13: Partial analysis of a battery storage showing the storage system utilization.

Figure 12 shows parts of the battery storage analysis. The system, in this case, consists of a standard load office building profile with a yearly load of 192 500 kWh/a and a PV power plant facing South and 30 degrees tilt with 50 kWp. The battery storage installed has a nominal charging power of 50 kW and a usable capacity of 100 kWh. Figure 12 shows a table, summarizing the battery system usage.

As an example, the first row in the table shows the SoC distribution of the BESS. The value distribution shows, that more than 75 % of the time, the storage is empty, meaning the storage has reached the DoD and there is no available usable capacity. Anyhow, the storage does get fully charged at some point, as the maximum reached SoC is 100 %. However, as the BESS is completely empty nearly all the time the following hypothesis should be reviewed:

- The BESS power is too low in comparison to the PV generation, such that the excess PV power cannot be charged;
- The PV excess generation is too small to sufficiently charge the BESS;
- The BESS capacity is oversized.

In this case, the first hypothesis can be excluded, as the nominal BESS power is 50 kW. According to the second row in the table, the maximum BESS power is 37.69 kW, which is well

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below the the nominal BESS power. The second hypothesis, that the PV excess power is too small to sufficiently charge the BESS can be verified by comparing the consumption and generation profile analysis. When comparing the two profile analysis it can be seen, that most PV generation is directly used to cover the energy consumption of the office building. Therefore, one of the results in this case would be, that the PV power plant is rather small, and that the installed BESS, when the nominal installed PV power is not increased, is not sufficiently utilised and will therefore most probably not lead to an economically viable use case.

Figure 12 further shows, that the battery power of 50 kW is not utilized in this system configuration, as the minimum battery discharging power in this system configuration only reaches 36.1 kW. The highest battery charging power reaches up to 37.69 kW. Concluding these observations, it can be said that, in this case, a BESS power of 40 kW would be sufficient for this configuration. By reducing the BESS power, the BESS is less often charged at partial load, increasing the charging/ discharging efficiency. Especially in ACDC grid systems and AC coupled PV power plants the efficiency of the converter is a major factor, as the PV power is converted from DC to AC and to be stored from AC to DC and back to AC when the BESS is discharged. The figure further shows the power distribution as value distribution and as cumulated distribution. Based in this, it can be seen that the BESS, and therefore the BESS converter, is in standby mode for more than 80 % of the time.

4.1.3 Application Analysis

The application analysis is the fourth HTML analysis. It evaluates the system operation strategy. The operation strategy in the Component Sizing Tool is self-consumption optimisation, meaning that the application analysis evaluates the amount of self-consumption as well as the amount of self-sufficiency. Further, the overall grid consumption and grid feed-in, as well as the maximum grid consumption and grid feed-in power are documented.

Figure 14 shows the generation, consumption power profile, as well as the resulting BESS power profile and the power profile at the PCC. The profile at the PCC does not yet include any losses for a possible DC/AC conversion nor any losses at the MVAC/ LVAC transformer.

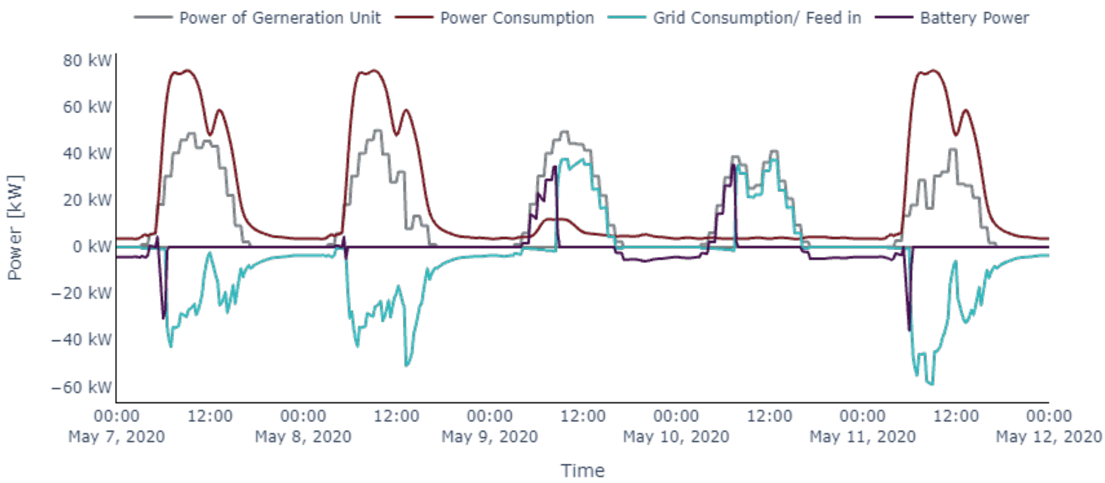

Figure 14: Partial analysis of the system application analysis, including a consumer, a generator and a BESS.

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In this case, the application analysis shows, that nearly 89 % of the PV generation is used by the office building on site. The self-sufficiency with nearly 28 % however is rather low, showing that the PV power plant indeed is rather small in comparison to the consumption.

4.1.4 Economic Analysis

The economic analysis evaluates the CAPEX and OPEX of each system component. The CAPEX does not only contain the initial investment costs, but also any further re-investments made within the simulation time horizon. Based on CAPEX, OPEX, the remaining system value and the amount of energy generation as well as consumption, the NPV and LCOE are calculated.

Based on these evaluations the user can not only size system components based on technical solutions, but also under the consideration of economic parameters and the overall economic viability.

4.2 Component Operation Output

At last, the Component Sizing Tool output is a CSV file containing detailed component operation data for each time step within the simulated time horizon. Part of the CSV file is the original generation and consumption profiles, the direct usage of PV generation, the resulting power profile of consumption and generation, as well as the BESS charging and discharging power, the charging/ discharging efficiency, the SoC in each time step as well as the BESS SoH. The unit of all these values is in kW, energy values are therefore given in kWh, power values in kW.

5 Tool Usage within HYPERRIDE

5.1 Demo Usage in HYPERRIDE

Figure 2 shows the system components which can be configured within the Component Sizing Tool. It shows the Load or consumption unit, the PV power plant, the BESS and the PCC. The PCC does not yet include any DC/AC converter losses, nor any MVAC/LVAC transformer losses. The load can either be an AC load or even DC load, as long as the necessary conversion is included within the consumption power profile. The PV power profile can either be entered as DC or AC profile as long as the user then chooses the relating system conversion efficiency. In case of a DC system, the conversion would be a DC-DC conversion. In case of an AC system the PV power would first be converted by a DC-DC converter and further by a DC-AC converter. The storage system also consists of a converter and the BESS. Similar to the PV conversion, the BESS converter would either consist of solely a DC-DC converter or the combination of a DC-DC and an AC-DC converter. In case of an ACDC hybrid grid, there would be an additional converter between the public grid, the transformer and the consumer side.

For the following example, the same system configurations were simulated, once for an AC grid and once for an ACDC hybrid grid. Therefore following parameters were chosen, starting from the top, going left to right in the online tool:

Table 1: General Configuration Input to the Component Sizing Tool.

Value	Input
Simulation Time Interval (dd.mm.yyy)	01.01.2020 - 31-12-2020
Consumption Power Profile	pre-defined consumption profile: Office building load profile, standard load profile by APCS with 192 500 kWh/a
Scale Consumption Profile	Use profile data
Generation Power Profile	pre-defined PV generation profiles: PV power plant, facing South 30° tilt, 1kWp installed
Scale Generation Profile	Use profile data

Table 2 shows how the same system configuration can be applied within an AC grid and an ACDC hybrid grid. System 1 was configured within an AC grid. This means, that the PV power generation is converted once with a DC-DC converter and in order to connect it within the AC grid, once with an DC-AC converter. Both conversions were assumed to have an average efficiency of 98 %, leading to an overall conversion efficiency of 96.04 %. The same accounts for the BESS converter, which was also defined with a conversion efficiency of 96.04 %. System 2 was configured within an ACDC hybrid grid. Therefore, only one DC-DC converter is accounted to interconnect the PV power plant and the BESS to the grid, as the DC-AC conversion is not necessary. The conversion efficiency of the PV and the BESS converter was also accounted with 98 %, but, as only one conversion is necessary, the overall conversion efficiency is also 98 %.

Table 2: System Configuration Input to the Component Sizing Tool.

Systems to Configure Value	System Configuration 1 AC Grid System	System Configuration 2 ACDC Hybrid Grid System
PV System configuration		
Set installed PV power	Scale generation profile 50 kWp	Scale generation profile 50 kWp
Set PV converter	96 % efficiency; 50 kW nominal converter power	98 % efficiency; 50 kW nominal converter power
BESS configuration		
Set BESS parameters	Nominal BESS system power 50 kW; Installed BESS system capacity 100 kWh; Initial BESS state of charge 50 %	Nominal BESS system power 50 kW; Installed BESS system capacity 100 kWh; Initial BESS state of charge 50 %
Set BESS converter	96 % efficiency; Nominal converter power 50 kW	98 % efficiency; Nominal converter power 50 kW

Table 3: Economic Parameter Input to the Component Sizing Tool.

Value	Input
PV Costs	
PV power plant investment costs in € per kWp including mounting	1430 €
PV converter investment costs in € per installed kW nominal power	200€
PV operational costs in € per installed kW nominal power	28.6 € p.a.
BESS Costs	
Battery storage investment costs in € per installed kW nominal power	113 €
Battery storage investment costs in € per installed kWh usable capacity	594 €
BESS converter investment costs in € per installed kW nominal power	200 €
BESS operational costs in € per installed kWh usable capacity	1.5 €
Electricity Costs	
Electricity costs in € per kWh, including network charges, taxes and levies	0.25 €
Feed in tariff in € per kWh	0.05 €

Table 4 summarises the technical simulation results of System Configure 1 and System Configure 2. When simulating both scenarios the results show, that the overall system efficiency of System Configuration 2, which is implemented in an ACDC hybrid grid, is higher than System Configuration 1. Further it can be seen, that less energy is fed into the grid and the self-sufficiency in System Configuration 2 is increased. This can be explained by the reduced conversion losses which can also be seen in the reduction of the Charging losses and Discharging losses. The self-consumption on the other hand is higher in System Configure 1.

Anyhow, this can also be explained by the increased amount of losses within the system, as the calculation of self-consumption accounts losses to energy consumed within the system. Further, as the conversion losses in System Configure 2 are reduced, more PV generation is available, leading to an increase of energy grid feed in. The Charged energy into the BESS is also higher in System Configure 1, anyhow, when looking at the amount of charging losses and the amount of discharged energy, it can be seen, that System Configure 2 is much more efficient than System Configure 1.

Table 4: System Configuration Results of the Component Sizing Tool.

Value	AC Grid System	ACDC Hybrid Grid System
Self sufficiency	27.37 %	27.13 %
Self consumption	88.47 %	88.61 %
Grid consumption	140 161.58 kWh	139 703.88 kWh
Grid feed in	6918.23 kWh	6999.0 kWh
BESS system efficiency	74.11 %	81.87 %
Total charged energy	6 273.45 kWh	5 989.77 kWh
Charging losses	644.33 kWh	468.44 kWh
Total discharged energy	4 649.26 kWh	4 904.05 kWh
Discharging losses	1 019.23 kWh	656.63 kWh

The further component sizing can be done by configuring the converters as small as possible, as explained in Section 4.1.2. Further technical and economic improvements can be achieved by increasing or decreasing the amount of installed PV and adjusting the installed BESS capacity based on the lowest LCOE or the highest NPV. Choosing the correct converter size however decreases the investment costs while increasing the system efficiency, choosing the right converter size is therefore fundamental when choosing configuring systems.

5.2 Future Usage in HYPERRIDE

The online Component Sizing Tool will be used to simulate different use-cases at pilot sites. As an example, it shall be used for the component sizing of the Italian pilot. Therefore, the consumption and generation power profiles for the Italian pilot were pre-defined in the online Component Sizing Tool, to increase the tool usability. By using the online Component Sizing Tool different system component sizes can be simulated, evaluated and finally compared.

Further, the Component Sizing Tool shall be used in addition to the Grid Planning Tool for the development of Hybrid AC/DC microgrids for BESS simulations. The implementation of the Component Sizing Tool in the Grid Planning Tool provides the connection between the grid and the behind the meter application which is not available in the Component Sizing Tool. Therefore different scenarios will be simulated by adding BESS configurations to the existing grid profiles. The resulting power at the PCC of the simulation is finally used as new input to the Grid Planning Tool. Thereby, the Component Sizing Tool helps to evaluate the possibility to reduce grid transformers and converters at the PCC through the usage of BESS. Further, the Component Sizing Tool will provide techno-economical BESS analysis for the implemented BESS configurations.

Last but not least, the Component Sizing Tool will provide techno-economical input data for the evaluation and comparison of HYPERRIDE business models. The Component Sizing Tool calculates the total amount of CAPEX, OPEX and revenue over the simulation time frame, based on these values, the Component Sizing Tool further calculates the NPV and the LCOE. These values will be used for evaluating the economic viability of different business models and system configurations within these business models. Therefore, AIT will run large, independent parameter studies based on the code behind the Component Sizing Tool for each relevant business case. AIT will further evaluate the results of these parameter studies and provide knowledge on how to configure the system components based on these parameter studies.

6 Conclusions

The Component Sizing Tool was originally developed for techno-economic evaluations of storage systems. Within HYPERRIDE, the Component Sizing Tool was extended specifically for ACDC hybrid grid applications. The Component Sizing Tool now simulates and analyses behind the meter system applications including generation power plants, consumers and a storage system. The interconnection of the system components can be defined by setting the overall conversion efficiency for the PV generation into the ACDC hybrid grid, as well as the energy conversion between the ACDC hybrid grid and the BESS.

By adding specific component CAPEX, OPEX as well as a FiT, if applicable, the Component Sizing Tool automatically calculates the total CAPEX, total OPEX for the simulation duration, and all revenues. Further, the NPV is calculated under the consideration of the remaining value of the system components at the end of the simulation time frame.

The online Component Sizing Tool currently works with one operation strategy, self-consumption, which is used for increasing the amount of PV generation directly used on site. Another operation strategy, peak shaving, already exists but was not implemented in the online tool due to the lack of performance. The further development of the Component Sizing Tool, therefore, will include a performance improvement.

Within HYPERRIDE, the Component Sizing Tool will be used for different pilot sites and business model and use-cases evaluations. If necessary, the Component Sizing Tool will be adapted to the HYPERRIDE use-case, such as adding power profiles for different pilot sites. Further, the code behind the online Component Sizing Tool will be used remotely to create large parameter studies, as the tool does not provide sufficient performance for large parameter studies.

Beyond HYPERRIDE, the Component Sizing Tool is used for different types of storage types such as hydrogen storages and thermal storages. Further improvements of the Component Sizing Tool, outside of HYPERRIDE, will also include the possibility to use multiple storage types, such as a combination of BESS and hydrogen, and possibly even the usage of excess heat of the electrolyser and the fuel cell.

Another future enhancement will be to adapt the Component Sizing Tool such that the Component Sizing Tool does an automated parameter study based on a few input parameters. The final goal for the Component Sizing Tool is to implement an optimization that will evaluate the best fitting technical solution as well as the system solution with the highest economic viability.

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