D4.4 - Initial Grid-side ESS Control System

Deliverable ID	**D4.4**
Deliverable Title	**Initial Grid-side ESS Control System**
Work Package	**WP4**
Dissemination Level	**PUBLIC**
Version	**1.0**
Date	**2018/08/30**
Status	**Final**
Type	**Report**
Lead Editor	**LIBAL**
Main Contributors	**LIBAL**

Published by the Storage4Grid Consortium

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731155.

Document History

Version	Date	Author(s)	Description
0.1	2018-06-25	LiBal	First draft
0.2	2018-08-02	LiBal	Changed system architecture and description of system components
0.3	2018-08-06	Fraunhofer	Review
0.4	2018-08-24	LiBal	Changes according to FIT's review Added new sections
0.5	2018-08-29	LiBal	Adapt EDYNA and ISMB's comments
1.0	2018-08-30	LiBal	Final version, ready for submission to the EC

Internal Review History

Review Date	Reviewer	Summary of Comments
2018-08-06 (v0.3)	FRAUNHOFER	Reviewed: • Comments on the architecture presented in this deliverable • Changes in the text • Comments on texts missing
2018-08-29 (v0.5)	FRAUNHOFER	Approved: • Changes in the text • Minor corrections
2018-08-29 (v0.5)	EDYNA	Approved: • General minor corrections

Legal Notice

The research work leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731155 - Storage4Grid project. The information in this document is subject to change without notice. The Members of the Storage4Grid Consortium make no warranty of any kind with regard to this document, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. The Members of the Storage4Grid Consortium shall not be held liable for errors contained herein or direct, indirect, special, incidental or consequential damages in connection with the furnishing, performance, or use of this material. The European Union and the Innovation and Networks Executive Agency (INEA) are not responsible for any use that may be made of the information contained therein.

Table of Contents

Executive Summary

D4.4 – "Initial Grid-side ESS control system" presents the prototype of the grid side control system and its architecture. The optimization framework and software implementation are being introduced in this document.

Grid-side energy storage system control system (GESSCon) is a decision-making module running in the cloud that is deciding the energy storage system charge/discharge behavior in the next 24 hours based on current local and grid situation. It works together with PROFESS (local agent) and DSF (Decision support framework).

Input data are supported by DSF, where predictive models provide forecast of energy demand and PV production according to user's historical data, electricity price is depending on the spot market locally and weather forecast comes from third party services. The output data – schedule for the next 24-hours, will be sent to PROFESS through the Control Broker. PROFESS will execute this schedule based on its own local knowledge.

In the following deliverable (D4.5 – "Final Grid-side ESS control system"), the final system structure will be presented, and the final algorithms will be implemented in the GESSCon. These algorithms will implement cooperative different grid code (electric network requirements in different countries), and they will also focus on maximizing renewable self-consumption, relieving grid congestion and prolonging battery lifetime.

1 Introduction

This document describes the grid-side energy storage system control system (GESSCon) prototype in Storage4Grid project. GESSCon is a decision-making software that take both grid status and local energy storage system condition into account and make charge/discharge suggestions for the next day. GESSCon will deliver a 24h schedule to the local control service (PROFESS) every hour. Therefore, PROFESS will control the energy storage system based on this schedule and its own optimization algorithms.

1.1 Scope

This deliverable "D4.4 - Initial Grid-side ESS control system" is developed under task "T4.2- Grid-side ESS control". It will be followed by a final prototype in deliverable "D4.5 - Final Grid-side ESS control system" in M32.

1.2 Related documents

ID	Title	Reference	Version	Date
[RD.1]	Final Storage Scenarios and Use Cases	D2.2	1.0	2018-07-31
[RD.2]	Initial Lessons Learned and Requirements Report	D2.5	1.0	2017-05-30
[RD.3]	Initial S4G Components, Interfaces and Architecture Specification	D3.1	1.0	2017-09-15
[RD.4]	Updated S4G Components Interfaces and Architecture Specification	D3.2	1.5	2018-08-08
[RD.5]	Updated User-side ESS Control System	D4.2	1.0	2018-06-14

2 Initial Grid-side ESS Control System Prototype Overview

Figure 1 illustrates the general structure of ESS control system in S4G project including Grid-side ESS control and Local-side ESS control. The grid-side ESS control will have an overview knowledge of both grid (DSO requirement) and local situation (local consumption and production), whereas the user-side ESS control will only focus on optimizing based on the local knowledge (energy inputs of the household as e.g SoC of the battery, input energy from the grid, etc.).

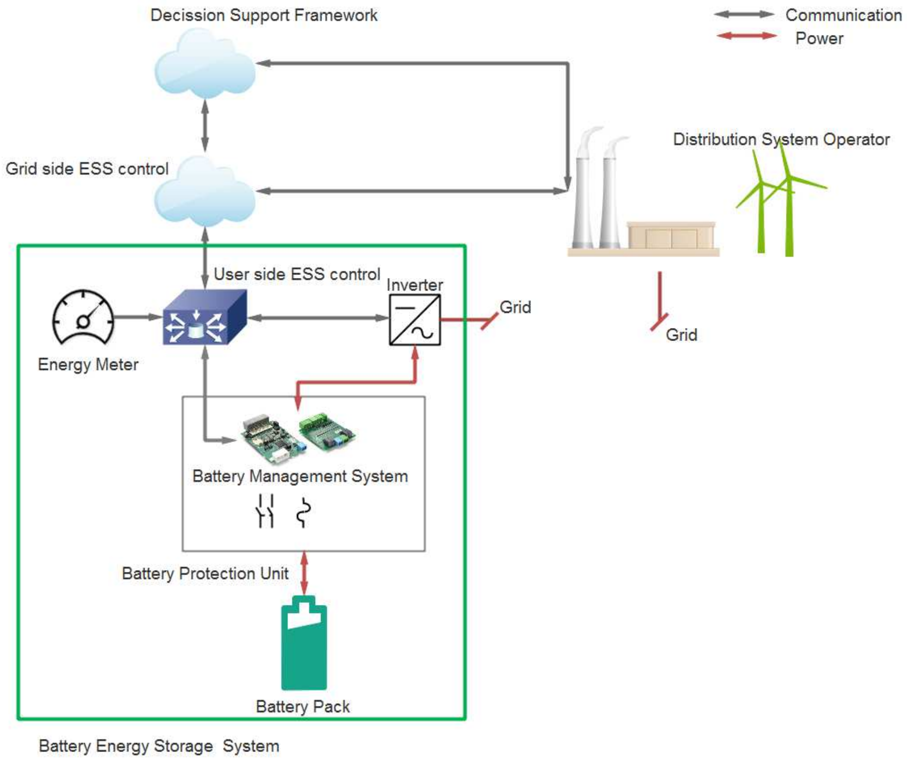

Figure 1 – Overview of ESS control system

2.1 GESSCon

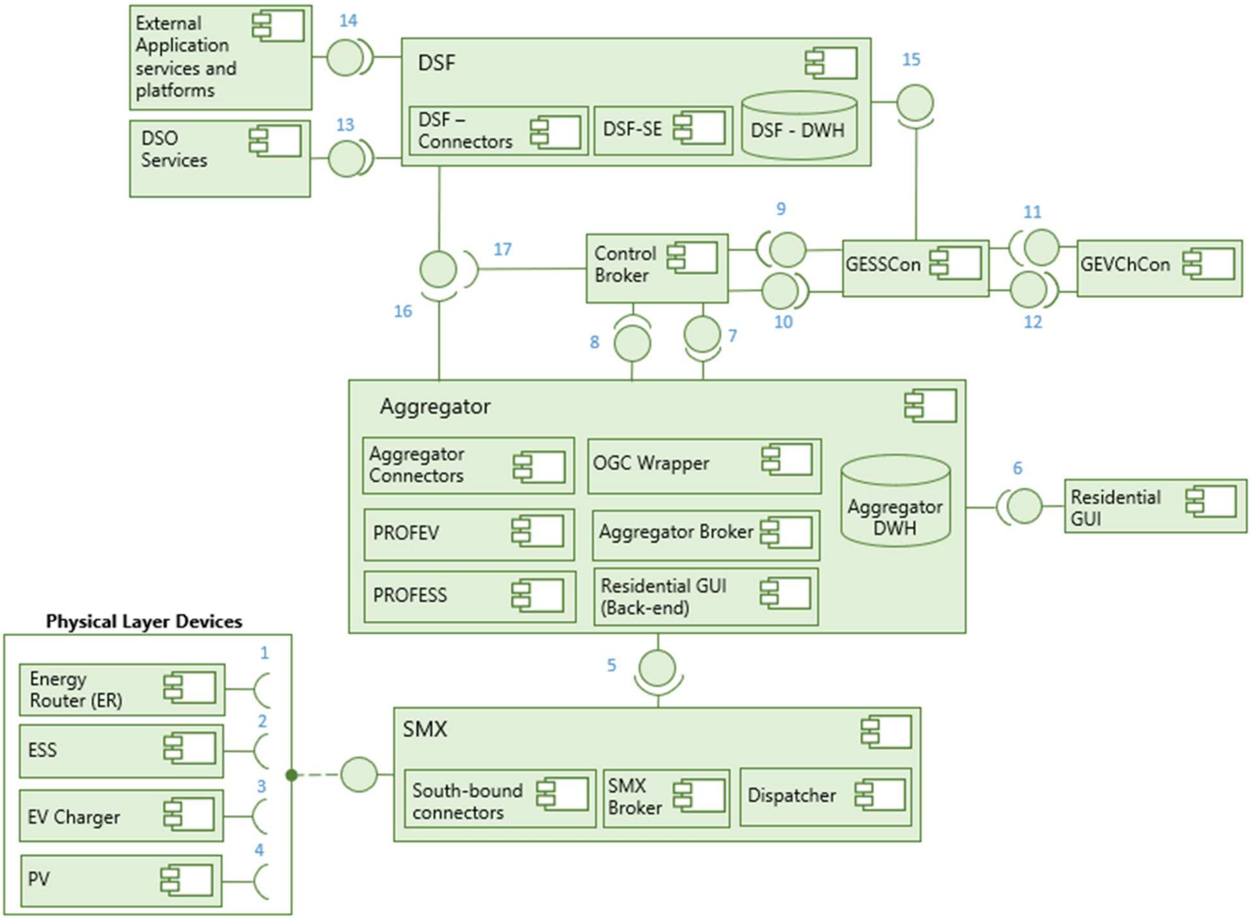

Figure 2 – Control view of S4G System

Figure 2 shows the architecture in S4G-Project and is described in "D3.2 - Updated S4G Components Interfaces and Architecture Specification". GESSCon is an important cloud component, which receives input from DSF such as 24 hours foresight on user's load profile, PV production, EV load and electricity price. The output data from GESSCon – a 24 hours schedule of charge/discharge of ESS will be published to the MQTT Control Broker. PROFESS will subscribe to the respective topic, so it can execute the ESS control schedule with PROFESS's own intelligence. In order to improve the accuracy of the schedule, GESSCon will receive a new 24 hours forecast every hour from DSF and make new 24 hours schedule to correct/update the previous schedule. This shifted window is expected to be able to both optimize the global operation schedule of ESS and allow energy system operating 24 hours with grid knowledge foresight off-line in case of losing internet connection. GESSCon is a program written in python, which is capable to operate in many different environments.

2.2 PROFESS

The PROFESS is a local optimization unit on each household. The PROFESS uses the energy information collected from smart meters by the USM, the global charging/discharging of ESS schedule from GESSCon and generates a local optimal control at user premises. South-bound connectors of the USM are in charge of executing the set-points calculated by the PROFESS. In most cases there is one PROFESS at each location but in some cases, there may be more e.g. if the ESS is located in two different rooms or buildings at the same location.

2.3 Energy Storage System

The energy storage system is one of the key physical components in S4G project. In the first versions the energy storage system is a battery storage but the principles of the GESSCon optimization can also be applied to other types of energy storage such as thermal storage (connected to heating/cooling components).

2.4 Energy Source

The Energy Source is a (local) energy production component, a PV in this project. In S4G project, one of the goals is to optimize the self-consumption of the energy source.
DSF will receive local weather forecast from a third party and estimate the energy source production in the next 24 hours as an important input parameter for GESSCon.

2.5 Grid connection

The system in this project is connected to the electrical grid. Electricity can be imported from and exported to the electrical grid.

2.6 DSF

DSF is a loosely-coupled collection of interoperable software components, integrated with the DSO SCADA and other relevant 3rd party data sources. They can be combined in different configurations to perform analysis, planning, forecast and optimization tasks of distributed storage systems

2.7 Data/Control broker

Data/control broker is a scalable software component handling dispatch of raw data from S4G field components to the grid-side components, in an event-oriented fashion. It is deployed and maintained as a private cloud service or on the premises of the entity operating S4G-based services (e.g. DSO or Aggregator). [D3.2]

3 Input data

There are two types of input data for GESSCon. One is real-time data of the local ESS situation from SMX, and the other one is forecast data received from the DSF. In this section, forecast data is introduced.

3.1 Demand forecast

User demand has strong connection with season, weather, temperature, user behaviour and so on (Staffell 2018) [2]. In order to have accurate forecast, user's own historical demand information is being used. DSF data warehouse will receive user's demand data from SMX and store them for later data processing/prediction.

3.2 PV production forecast

PV production is a very sensitive data. It is directly link to the weather, location and the mounting angle of solar panels and so on (Alet 2017) [1]. A weather forecast is obtained from a third party, which contains information such as solar irradiance, temperature and so on. Geographical position and PV system parameters are known for the DSF.

3.3 Electricity retail price forecast

Electricity price forecast is normally based on spot market price or pre-determined pricing scheme. Spot market price is an equilibrium of demand (willing to buy) and supply (willing to sell). It varies from time to time, which can illustrate the grid congestion situation from another angle. However, from user's point of view spot market price still has some distance to the real electricity price, which is missing VAT, tax and other service fee. In this project, electricity price is obtained locally, which will provide a more accurate result. Pre-determined scheme instead, defines prices based on for instance timing slots, contract type, power and voltage level, reactive power, etc.

3.4 Electricity selling price

Electricity selling price in this project means solar feed-in tariff – excess renewable energy sells to grid price. Feed-in tariff in different country has different price and policy. It can be split into 2 scenarios. When feed-in tariff is zero, the user will optimize their renewable consumption by avoiding buying electricity from the grid. When feed-in tariff is not zero, depending on the electricity price the user can inject energy to the grid to make some profit.

4 Output data

GESSCon will send a 24h charge/discharge schedule to PROFESS every hour, in order to optimize end user's profit and relieve grid congestion. The data resolution of the output data is related to the input data resolution, which comes from the DSF.

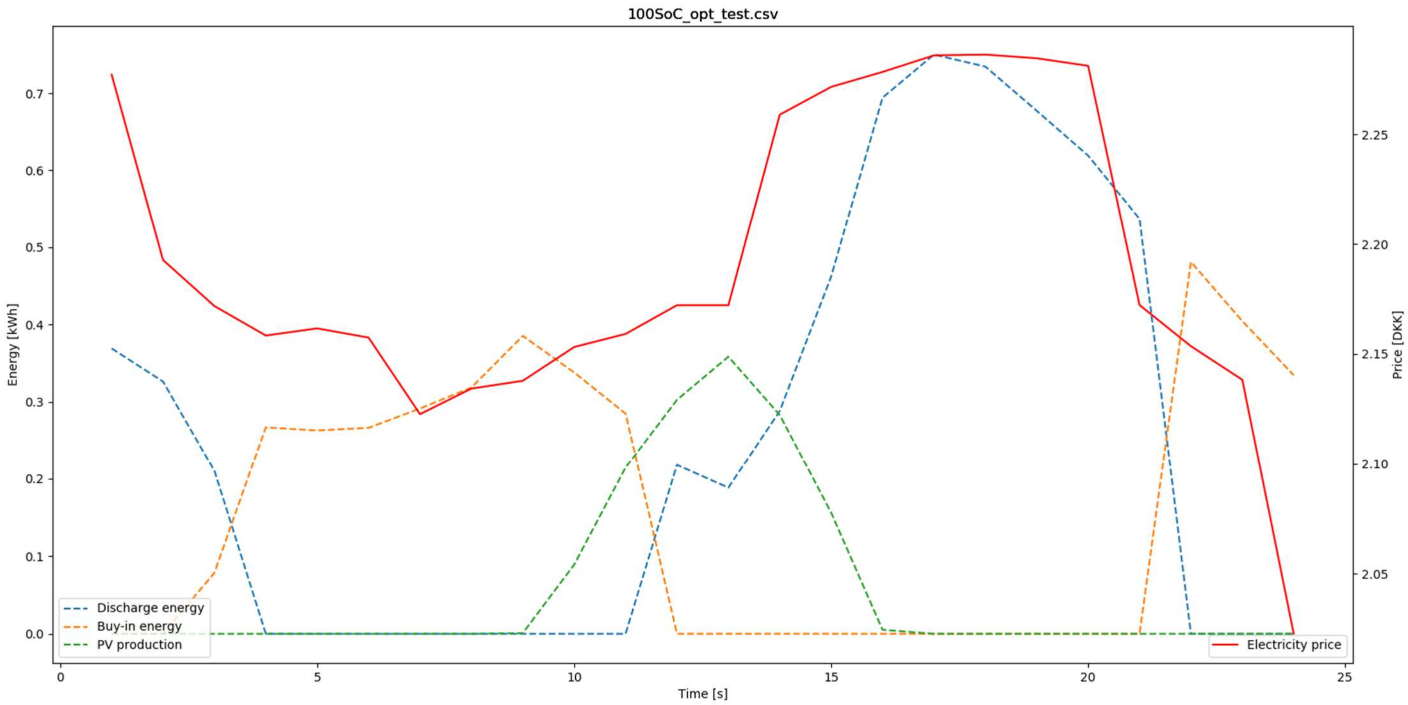

Figure 3 – GESSCon output example

As illustrated in Figure 3, the direct output from GESSCon are the orange and blue dash line in the plot, where the orange dash line represents the energy buy-in from the grid, the blue dash line is the discharge energy from the ESS. It is seen that the ESS is avoiding buying electricity when the electricity prices (red line in Figure 3) are high and the ESS is trying to cover all the high price period which is in the early morning and in the evening in this example.

An operation schedule/suggestion of the energy storage system is post calculated according to GESSCon's direct output. Each PROFESS will receive its own energy storage operation schedule according to their 24 hours foresight input from DSF.

5 Optimization algorithm

The objective of the optimization of the ESS usage is to minimize the overall cost of energy consumed (or maximize the value of energy sold). This is done by operating the ESS (charging and discharging the energy storage) in the most optimal way, based on the available information introduced in section 3. The optimization will be based on forecasted information that may be not precise. Therefore, the operation of the ESS may not turn out to be optimal under the actual conditions (actual consumption and production).

The GESSCon calculates a schedule for the local PROFESS (one schedule for each PROFESS). The actual control of the ESS is performed by the PROFESS and specified in "D4.2 Updated User-side ESS Control System".

The GESSCon algorithm is formulated as a mixed integer linear programming (MILP) problem and consists of an objective function and a set of constraints. The objective function contains 3 sections:

- maximizing renewable self-consumption: Direct
- relieve power congestion in the grid: Direct
- charging ESS when electricity market price is low: Direct
- prolonging battery lifetime: Indirect
- remain grid stability by preventing systems discharging to the neighboring systems which charging is high: Indirect

The constraints are formed by different technical and economical limitations of the energy storage system, which includes energy balancing, energy storage operation constraints, grid-side constraints and so on.

6 EV included optimization

In the original system architecture "D3.1 - Initial S4G Components, Interfaces and Architecture Specification", a parallel module to GESSCon - GEVChCon is in charge of all use cases that has EV involved in this project. However, during development it is found that EV cannot be handled alone in a separate module in the system. Therefore, GESSCon will also include EV cases in its optimization model. Aggregated EV load prediction will be an additional input to GESSCon for EV involved use cases. This prediction data is provided by DSF as well, similar to other forecast data.

7 Implementation

The mathematical model is interpreted in Python by using Pyomo package as a mix integer linear programming (MILP) problem which contains continuous real variables, integer variables, and binary variables. A number of input parameters such as electricity retail price, residential demand, PV production, feed-in tariff will be used to simulate the energy storage behaviors and return the optimal objective result back. GESSCon is a stand-alone program, which can run in all operating systems. There is no specific requirement on hardware. The GESSCon exposes a REST API so other systems can request charge schedules on demand. In operational mode, the GESSCon collects needed data via REST calls to the DSF connectors and also utilizes MQTT protocol to retrieve needed input data from the data broker such as ESS values. Based on the inputs the OR (operation research) Model computes the Chargeschedule which is published to the control broker via MQTT protocol.

8 Installation/Deployment

The GESSCon OR Model uses a container architecture which simplifies its deployment. Images of the software are uploaded into an Azure Container registry. The image is downloaded by an Azure Logic App which runs the docker image containing the OR model.

9 Software dependencies and requirements

Similar to PROFESS which is described in "D4.2 - Updated User-side ESS control system", no special hardware requirements are needed to implement the Grid-side ESS control. Software dependencies can be found in Table 1.

Dependency	License	Role
Docker	Apache License 2.0	Docker is used to facilitate the build process of the container image.
Python, image based on "Jessie"	GNU General Public License (GPL) 2.0	The operating system of the OR Model used as Core controller operating system.
Microsoft Azure	Pay-as-you-go	Connecting with IoT Hub and using Azure Logic App

Table 1. Software dependencies

10 API Reference

10.1 REST API

POST /Chargeschedule

Input Data: OCG compliant Json format with parameters from Table 2 below.

Return Data: OCG compliant Json format with parameters from Table 3 below.

10.2 OR Model parameters

Table 2 and Table 3 are input and output data of GESSCon which should be applicable to all use cases and simulation engine DSF-SE described in D2.2. GESSCon is able to handle several PROFESS at the same time, however it requires corresponding input data for each site/ESS can arrive to GESSCon as expected.

Variables (with units)	Data Type	Input Type	Description	Source	Periodicity	Note
Demand/Load [kWh]	Float	Forecast	Forecast data from DSF	DSF	Every one hour send a forecast array with 24 data points.	For residential case that each house has individual PV and home battery, data should be sent as a
PV production [kWh]	Float					
Electricity Price [Local currency]	Float					
Feed-in Tariff [Local currency]	Float					

						table/vector, where y-axis stands for time, x-axis stands for house ID.
SoC [%]	Float	Real Time Data	Real time data from ESS	SMX/Data Broker	Every one hour, should arrive same time as the forecast	
Grid Connection In [kW]	Float	Event Data	Event data from ESS and Grid	SMX/DSO	Send every time there is a change made	DSO should provide these information
Grid Connection Out [kW]	Float					
ESS Efficiency	Float					Mainly inverter round trip efficiency
ESS Max Operation Limit [kWh]	Float					Recommended operating ESS between 20% to 80% of its capacity
ESS Min Operation Limit [kWh]	Float					
ESS Max Charge Limit [kW]	Float					
ESS Max Discharge Limit [kW]	Float					
Energy losses [ratio]	Float					Depends on the grid topology and cables. When it has set to be zero, means no transmission loss is taken into account.

Table 2. Input data for GESSCon for use cases and simulation

Variables (with units)	**Data Type**	**Output Type**	**Description**	**Directions**	**Periodicity**	**Note**
Charge/Discharge Power [kW]	Float	Chargeschedule	Charge/Discharge Control of ESS	GESSCon → Control Broker	Every one hour send a control array with 24 data points.	Three dimensional dataset, contains Time, PROFESS ID and Power. Charge power shows in positive number, discharge power shows in negative number. Example of charge

						schedule can be found in BSCW.

Table 3. Output data for GESSCon for use cases and simulation

11 Conclusions

This document describes the structure of D4.4 – Initial grid-side ESS control system, the relation between GESSCon, PROFESS and DSF, the optimization algorithm and the input/output data of GESSCon. A final version D4.5 – Final grid-side ESS control system will be presented in M33 which contains more detailed description of the system and the result. The current developed modules will be extended and updated in order to provide more features, necessary for the Storage4Grid project.

Acronyms

Acronym	Explanation
API	Application Program Interface
BMS	Battery Management System
DSF	Decision Support Framework
DSO	Distribution system operator
SE	Simulation Engine
ESS	Energy Storage System
GESSCon	Grid ESS Controller
GEVChCon	Grid Electric Vehicle Charging Controller
MQTT	Message Queuing Telemetry Transport
OR	Operation Research
PROFESS	Professional Realtime Optimization Framework for Energy Storage Systems
RES	Renewable Energy Sources
REST	Representational State Transfer
S4G	Storage4Grid
SMX	Smart Meter eXtension
SoC	State of Charge
USM	Unbundled Smart Meter

List of figures

List of tables

References

[1] Alet, P-J., Efthymiou, V., Graditi, G., Juel, M., Moser, D., Nemac, F., ... Yang, G. 2017. «Assessing the need for better forecasting and observability of pv.» [*https://www.sciencedirect.com/science/article/pii/S0360544217320844?via%3Dihub*] .

[2] Staffell, I., Pfenninger, S. 2018. «The increasing impact of weather on electricity supply and demand.» *Energy*, Volume 145, 15 February 2018, Pages 65-78. [*http://orbit.dtu.dk/files/133414523/170503_Grid_Integration_WG_white_paper_web.pdf*].