Platone

PLATform for Operation of distribution NEtworks

D5.3 v1.0

Definition of Use Case Algorithms

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Abstract

This document describes the functionality and motivation of UC algorithms to be implemented and tested. The algorithms will enable a community or a low voltage network to operate in a virtual island mode, to provide flexibility on demand of external requests and enables an energy import and export in bulk at predefined times. The deliverable describes in detail the algorithms and the motivation for each Use Case. It further gives an updated overview of the actors, solution design, components, data to be processed and IT-infrastructure.

Keyword list

Islanding, Local Energy Community, Flex Provision, Algorithm, Islanding, Balancing,

Executive Summary

Distribution System Operators (DSOs) face challenges regarding the integration of Renewable Energy Sources (RES) into the existing distribution networks. Especially in low voltage (LV) grids, the amount of installed generation capacity is increasing. Over the coming years, the increase is expected to continue, creating even more stress on low and medium voltage (MV) feeders and transformers. Additionally, the electricity demand in distribution grids from residential and small commercial customers is expected to increase beyond today's peak load levels. One way to deal with these challenges is to extend and reinforce existing grid infrastructures, which requires high investments and consequently will increase grid charges for the customer. With the Use Cases (UC) presented in Platone, Avacon's aim is to investigate innovative strategies of flexibility management, grid operation and the utilization of flexibility to keep the inevitable increase in costs to a minimum, taking into account the evolving role and behaviour of customer and prosumers.

In the coming years the demand of private households connected to the LV grid to participate in Local Energy Communities (LEC) or Citizen Energy Communities (CEC) in order to optimise consumption of locally generated energy will increase. The German demonstrator of Platone and the associated use cases welcome this innovative development and explore efficient ways of integrating energy communities into the distribution grid. This will enable the creation and growth of these communities and their integration into future grid operation strategies aiming to provide electricity reliably, safely and efficiently.

In the context of the German field-test trial of Platone, Avacon will upgrade a rural LV grid with all assets required to operate a local energy community. The core of the demo will be a newly developed energy management system (EMS) named Avacon Local Flex – Controller (ALF-C) which monitors and controls the power flows within the community and between the community and the MV-feeder.

The ALF-C will be implemented in a digital environment and provide next level functionalities by applying newly developed algorithms., thus enabling a wide range of functionalities and application of specified use cases:

- UC 1 (Virtual Islanding) focuses on the demonstrator's ability to manage an energy community and to use the local flexible assets to maximise the consumption of the locally generated energy and minimise the energy exchange along the grid connecting feeder to a minimum.
- UC 2 (Flexibility Provision) explores the ability of the ALF-C to provide access to the aggregated flex portfolio of an energy community, to coordinate the activation of flexibility with centralised mechanisms of grid management, flexibility management or markets and maintain a fixed setpoint of load exchange with the distribution grid.
- UC 3 and 4 (Bulk Energy Import and Export) take into account that energy communities will still require some degree of exchange with the distribution grid, either to export surplus energy during times of high local generation or to import energy to cover a deficit likely to arise during winter. These UCs will investigate the degree to which the import and export can be organised in bulk packages by assigning fixed windows of grid access to energy communities.

This report describes in detail the design of the system, UC algorithms and underlying optimization problems as well as functionalities to be implemented by algorithms. These will be subsequently tested and refined during the field-testing phase in the German Demo of Platone.

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1 Introduction

The project “PLATform for Operation of Distribution Networks – Platone - aims to develop an architecture for testing and implementing a data acquisition system based on a two-layer approach (an access layer for customers and a Distribution System Operator (DSO) observability layer) that will allow greater stakeholder involvement and will enable an efficient and smart grid management. The tools used for this purpose will be based on platforms able to receive data from different sources, such as weather forecasting systems or distributed smart devices spread all over the grid area. These platforms, by communicating with each other and exchanging data, will allow collecting and elaborating information useful for DSOs, Transmission System Operators (TSOs), customers and Aggregators. In particular, the DSO will invest in a standard, open, non-discriminating, economic dispute settlement blockchain-based infrastructure, to give to both the customers and to the aggregator the possibility to become flexibility market players more easily. This solution will see the DSO evolve into a new form: a market enabler for end users and a smarter observer of the distribution network. By defining this innovative two-layer architecture, Platone removes technical barriers to the achievement of a carbon-free society by 2050 [1], creating the ecosystem for new market mechanisms for a rapid roll out among DSOs and for a large involvement of customers in the active management of grids and in the flexibility markets. The Platone platform will be tested in three European trials in Greece, Germany and Italy and within the Distributed Energy Management Initiative (DEMI) in Canada. The Platone consortium aims to go for a commercial exploitation of the results after the project is finished. Within the H2020 programme “A single, smart European electricity grid” Platone addresses the topic “Flexibility and retail market options for the distribution grid”.

This deliverable takes a closer look at the role of the DSO. It describes how the energy management system can be designed and how the energy management system can look like. For this, the balancing mechanism and their algorithms for different use cases that occur in a future energy community are described.

1.1 Task 5.3

Continuing from the overall design of the technical solution and use case descriptions developed in Task (T) 5.2, T 5.3 focuses on the development of the algorithms required for implementation of functions for the use case application. The description of the logical approach, optimization problem and required calculation and processing of data from the field are the key of the algorithm and implementation of Use Cases 1 to 4 (T5.3.1, T5.3.2, T5.3.3 and T5.3.4) in the field-test phase.

D5.3 gives an updated overview of components to be used in the field test, including technical data and characteristics relevant for the use case algorithms. It further provides an overview of the IT-architecture to create a better understanding of the algorithms.

1.2 Objectives of the Work Reported in this Deliverable

This deliverable provides a description of use cases to be implemented in the field-test phase, an updated description of the solution design, components in the field and processed data. Furthermore, the deliverable describes in detail the logic of the algorithms for each use case, motivation, applied calculations and optimization problems to be solved as well as a mathematical description the algorithms. The algorithms will be further developed and finalised in M24 (August 2021).

1.3 Outline of the Deliverable

Chapter 2 describes the general objectives and motivation of UC algorithms and background of the UC concept.

Chapter 3 gives an overview of the field-test components, a description of roles, provides key data of relevant assets and their characteristic relevant for the algorithms. It gives an overview of load flows, definitions of variables and regulations about the sign of variables with examples.

Chapter 4 gives an update of the framework architecture that includes an overview of the ALF-C in the Platone framework, relevant modules of the ALF-C, their functions and implementation, and data flows.

Chapter 5 describes for each UC in detail the logic steps of each UC algorithm to be implemented, including description of calculations to be processed and graphical visualizations and references to functional algorithms to be implemented.

Chapter 6 gives an overview of functional algorithms for balancing, dispatching and forecasting.

Chapter 7 presents the conclusions of the deliverable.

1.4 How to Read this Document

For more information on Platone, please refer to the Grant Agreement [2]. This document reports the algorithms of the use cases implemented within work package (WP) 5. An initial concept of the solution design and technical specification of the architecture was provided in D5.1 [3]. More information about the Use Cases performed and KPIs for the evaluation of the Use Case data and measurement results can be found in D5.2 [4] and D1.2 [5]. More information about the dependencies of this work package with the others, D9.4 can be read, since it lists all tasks and dependencies of all work packages.

First results and evaluations of the algorithms will be published within the D5.4 in M24.

2 Objective and Motivation

2.1 General Objective and Motivation

The main target of the German Demo is to develop, test and evaluate a local balancing mechanism for a low voltage (LV) grid with high penetration of Distributed Energy Resources (DER)—the foundation of future Local Energy Communities (LEC). The consideration of the subsidiarity principle for energy supply is an essential part of the developed local energy balancing. This is addressed by the usage of DSO-operated energy storages, privately-owned storages and a decentral control instance that takes the flexible consumer demands into consideration. This combination allows the consumption of locally generated energy to be maximised. Moreover, allocation strategies for flexibilities between networks of LECs are required to operate the distribution grids safely and reliably by alleviating extreme power and voltage peaks. By utilizing the flexibility of DERs and handling the energy import and export in bulk packages, it is possible to energetically decouple the local LV grid from the MV grid by minimizing the energy flow from the MV grid into the LV grid except for controlled periods of energy exchange. The main objective of this work package is to develop a decentralised controller to manage the energy exchange between an LEC and the MV grid, allocates the available flexibilities and handles requests. Four uses cases are developed that translate the most important requirements of the future LV grids into explorable scenarios. These use cases will form the basis for a subsequent field-test that will demonstrate and evaluate the concept of LECs with decentralised grid management.

UC 1 aims to show how energy communities can introduce a principle of subsidiarity by minimizing the absolute energy exchange at the LEC subgrid station. UC 2 then represents a second level of distribution management, which treats the entire LEC, or LV grid section, as a single source of generation, demand and flexibility. In doing so, Platone reduces the complexity of the control framework and the number of communication channels in pursuit of an efficient and future-proof approach to distribution management. UCs 3 and 4 introduce a new paradigm of energy supply that bases on a scheduled import or export of energy in bulk. The mechanism shall contribute to increase efficiency and quality of energy supply in distribution grid.

Figure 1 shows a concept of a future grid operation consisting of centralised and decentralised grid management instances. Therein, conventional grid control is responsible for controlling, monitoring and processing of measurements and status data of assets in the HV and MV grid, whereas decentral EMS will be responsible for these tasks on the community level for a bounden LV grid section. Each EMS is able to aggregate households and the portfolio of DER and flexible assets to an LEC. Moreover, each EMS provides an interface for interactions of DSO or TSO grid control and external electricity market participants or aggregators.

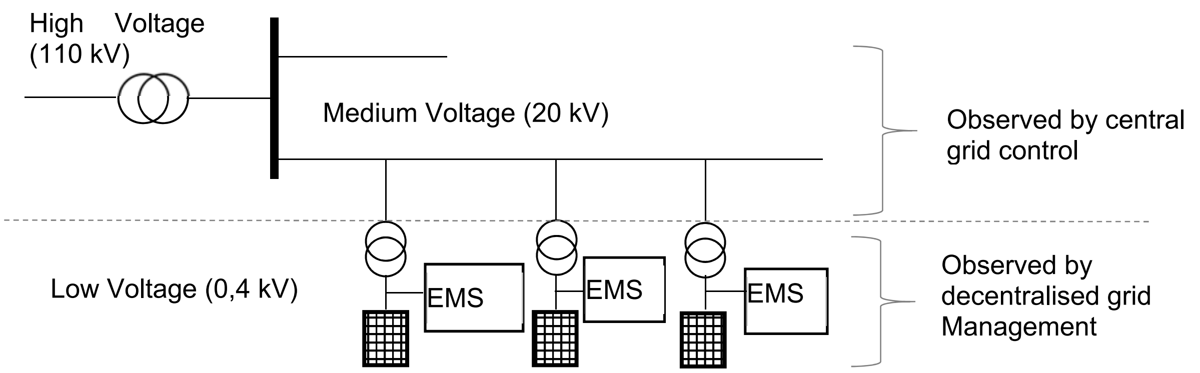

Figure 1: Responsibilities of centralised and decentralised grid management

2.2 Use Case 1 – Virtual Islanding

Today, distribution grids are already challenged by the high amount of fluctuating feed-in from DERs connected to MV grid. Even in LV grids, the amount of generation and demand increasingly leads to additional stress on MV grid lines and feeders. These challenges result from the increasing number of privately-owned small-scale generators such as roof top photovoltaic (PV) systems and small-scale flexible loads such as heat pumps connected to LV grids. In future, the challenges will increase since more and more households will own a roof top PV system. At the same time, the load demand in LV grids will rise as a result of the increasing share of electric vehicles in the mobility sector requiring charging stations connected to LV grids. Additionally, oil heaters will be replaced by heat pumps, coupling the power and heat sector.

Within Use Case 1 “Virtual Islanding”, customer households and privately owned DER are connected within a LEC, able to generate, consume and share energy and maximise consumption of the locally generated energy and reduce power peaks at the LV/MV grid connection point. This UC investigates the effect of load flow changes of a LEC on the MV grid and test forecasting and balancing functionalities that pre-requisite for UC 2, 3 and 4. The UC will be implemented in two steps with different functional principles. More information about Use Case 1 – Virtual Islanding can be found in Platone deliverable D5.2 [4] and Platone deliverable D1.1 [6].

Table 1: Scope and objectives of use case 1

Scope and objectives of use case 1	
Scope	• Simulation of an Energy Community generation and consumption behaviour (virtual islanding) and investigation of effects on load flows in distribution grids • Optimization of energy consumption on community level and its effect on load flows at grid connection point • Enabling the integration of community flex pools into centralised grid management mechanisms for optimization of grid operation; for more reliable grid, increasing hosting capacities, reducing demand for extension, grid reinforcement

Objective(s)	• Virtual Islanding: Maximise self-consumption within an energy community
	• Minimise power exchange along MV/LV grid connecting feeder
	• Implementation of 2 different control schemes:
	  • Step 0 – based on real time measurement-/steering cycle
	  • Step 1 - based on 24-h setpoint schedule based on forecast.

2.3 Use Case 2 – Flexibility Provision

The future distribution grid will require an increase demand of system operators (DSO and TSO) to access small scale flexible assets and integrate them in centralised grid control mechanisms in order to maintain overarching system stability, secure system performance, and maintain efficient operation of distribution networks. The ALF-C will be able to balance a bounded lower voltage grid section or LEC and treats the LEC as a single source of flexibility. An integrated scheduler will enable the coordination of flexibility requests sent by third parties such as DSO, TSO, market participants or aggregators. The active request is subsequently disaggregated into individual control commands for available flexibility sources in a given local energy community with the goal of maintaining an externally defined non-zero setpoint for the power exchange at the MV/LV point of grid connection. More information about Use Case 2 – Flexibility Provisioning can be found in Platone deliverable D5.2 [4] and Platone deliverable D1.1 [6].

Table 2: Scope and objectives of use case 2

Scope and objectives of use case 2	
Scope	• Simulation of an Energy Community in distribution network to flexibility demands. (Optimization of energy consumption on community level and its effect on load flows at grid connection point) • Coordination of local flex activation with centralised mechanism of flexibility management and grid management
Objective(s)	• Coordination of simultaneous request for flexibility activation by third parties (DSO, TSO, market participants, aggregator) • Maintaining a non-zero power flow at the LV/MV grid connection point

2.4 Use Cases 3 and 4 - Bulk import/export

One of the biggest challenges in the operation of distribution networks with high shares of DER is the stochastic nature of a network demand that is modulated by local production. While networks consisting of consumers and loads with standard load profiles can be planned and operated rather reliably, high shares of DER introduce an element of uncertainty that makes it difficult to plan and design networks efficiently. Uncertainty in the planning process must lead to over dimensioning of assets to account for the risk of unexpected load configurations. Another challenge arises with the expected increase of peak loads in local low voltage grids arising from the increasing number of heat pumps, charging points for electric vehicles or other sector coupling technologies. New strategies for the increase of hosting capacity of existing grids are needed in order to enable the integration of these technologies in future.

One way to reduce uncertainty, increase hosting capacity of existing grid efficiency and reliability in network planning and operations, is to leverage flexibility and smart control algorithms to uncouple the LV grids from its MV-feeder by employing a package-based approach for energy supply. The residual demand of a network after local production can be forecasted and delivered to the network in bulk in advance. The energy can be stored in local batteries from which customers can withdraw energy as they please without affecting the MV-feeder. More information about Use Cases 3 and 4 – Bulk import/export can be found in Platone deliverable D5.2 [4] and Platone deliverable D1.1 [6].

Table 3: Scope and objectives of use cases 3 & 4

Scope and objectives of use case 3 & 4	
Scope	• Simulation of an Energy Community in distribution network to bulk import/export of energy. (Optimization of energy consumption on higher grid level).
Objective(s)	• Virtual Islanding: Maximise self-consumption within an energy community including bulk import/export • Minimise power exchange along MV-/LV-grid connecting feeder.

UCs 3 and 4, “Bulk import/export”, focus on importing and exporting energy to and from the local network in bulks within fixed time slots. The concept bases on an interaction between centralised and decentralised grid management. The centralised grid management is responsible for an efficient and reliable energy supply in distribution grid. It monitors HV and MV grids and ensures that the grid is operated within the technical limits. Whereas today’s LV networks are not directly monitored by centralised grid control SCADA/ADMS of the DSO, it is expected that in future the demand for monitoring and control mechanism will rise, caused by the increasing amount and changing characteristics of generation and demand in LV grid and their effects towards the superimposed MV grid.

The concept of Avacon to be tested within WP 5 consists of a centralised and several decentralised grid management instances. The central grid management observes the HV and MV network whereas decentral EMS systems are responsible for monitoring and balancing of bounded LV grid sections or even LEC. Figure 1 outlines the concept within the UC 3 and 4 approach. The central grid control (GCC) defines times slots for the import and export of power along the MV/LV feeder at the grid connection point from the LV networks I, II, III or LEC. Outside the time slot, the local EMS minimises the power exchange along the grid connection point. The EMSs (e.g. ALF-C) are responsible to maximise consumption of local generation and consumption and determine the most optimal balancing approach in order to apply the ex-ante bulk energy import (UC3) and ex-post energy export (UC4).

Use Case 3 approach focuses on time shifted bulk approach in load driven LV networks, which display a low share of generation in relation to the local consumption. Relevant grids are characterised by energy deficits to be served by the MV grid. Within this use case’s approach, the residual demand of a LEC after local production shall be forecasted and be delivered to the network in bulk in advance within fixed time slots set by a CGC. The ALF-C forecasts generation and demand for its responsible LV network. With a forecasting element, the ALF-C determines deficits and the required amount of energy that has to be imported during the periods set by the central grid control for energy exchange with the MV grid. The imported surplus of energy will temporarily be stored in local batteries from which customers can withdraw energy as they please without affecting the MV-feeder. Use Case 4 aims at reducing stress on MV-network lines and feeders in generation driven distribution networks. Generated surplus shall be exported out of the community into the MV network at fixed time slots set by CGC, e.g. night-time, when the stress on MV line and transformer is low.

3 Field-test Components and Definitions

For an effective implementation of UC and allocation of activation of flexible assets in the field, the UC algorithms have to enable the ALF-C to consider characteristics of generation and consumption behaviour of actors and components in the field. Therefore, Avacon aims to implement a field-test trial in an environment that represents of the future decentralised energy system of Avacon service grid and will be most likely found anywhere in Europe in the future so that the results can be transferred to other and larger areas with more customers. For the identification of a suitable environment, the following criteria have been defined:

- The area reflects the characteristic network topology and components of a medium and low voltage network of Avacon's service grid.
- The field-test area should reflect the rural generation and consumption structure, which is made up of individual households of private customers and agricultural buildings.
- The grid area should be characterised by a high generation capacity made up of PV systems, which temporarily leads to an excess of generation.

After an extensive research process, a LV network area was selected for the field-test trial and the establishment of the energy community. The field-test trial and energy community are made up of various components integrated into the use case algorithms. The role and characteristics of each component is described in deliverable D5.2 and deliverable D5.1. The components and relevant characteristics are specified in the following sections.

3.1 Field-test Assets and characteristics

3.1.1 Households and Agricultural Buildings (Household Demand)

Households and agricultural buildings are an essential component of the energy community within the field-test area. They are the consumers of energy and are considered a passive consumption component. The total consumption within the field-test grid section, aggregated at the network connection point, is mainly caused by households. Within the selected field-test region the LV grid of the energy community contains 228 network connection points with approximate 93 households and 2 agricultural buildings. Based on the available network and consumption data from databases of Avacon, the total annual consumption of the energy community, aggregated at the grid connecting MV/LV transformer can be estimated with 585,000 kWh for 2021. The individual power requirement and the annual consumption amount of a household are based on the type and size of the building and the number of people. The consumption behaviour of each household can be described with a standard load profile for private customer households, whereas the load consumption behaviour of buildings of farmers can be describes with a standard load profile for agricultural buildings. The power consumption caused by households or agricultural buildings in the field-test network area will not be influenced by the ALF-C within the UC application. Households and agricultural buildings therefore can be characterised as a passive, non-flexible load. Consequently, the load demand of households and agricultural buildings located within the field-test area remains unaffected from active or passive participation in the LEC.

3.1.2 Photovoltaic (Generation)

Agricultural buildings or households in the field-test area are partially equipped with a PV system. The electricity generated is partly used directly for self-sufficiency, temporarily stored in household battery storage for delayed self-sufficiency or directly fed into the community's LV grid. Based on network data from Avacon's databases, the installed generation capacity of all PV systems that are connected to the LV grid of the field-test area, and thus the total generation capacity of the energy community, is 302 kW. At the current stage no measurement data are available from which the total annual generation of energy can be derived. Generation will be taken as given and not influenced during the use case application in the trial.

3.1.3 Smart Secondary Substation (Grid Connection Point)

The grid connection between LV grid of the LEC and the feeding MV grid is located in the smart secondary substation. Since the LV grids in Avacon's service region are operated as open ring networks, the energy demand of the field-test grid section is supplied via this single grid connecting point. The substation consists of a housing, a MV connection, an adjustable local transformer, a low voltage busbar as well as measurement and communication technology. Measurement technology with sensors will be installed on the low voltage busbar, metering the residual load demand after local generation and consumption. Measurement data are transmitted for monitoring via an LTE Modem to the ALF-C.

3.1.4 Community Battery Energy Storage (CBES)

A large battery energy storage will be implemented in the field-test region to provide necessary power and storage capacity to balance the local grid, even in case customer households will not be available to provide any flexibility. In the frame of use case application, the storage will provide storage capacity and ramp up and ramp down power for:

- buffering of energy surplus generated within the local network,
- balancing of local generation and demand,
- current active power supply, and
- buffering bulk energy.

Rolls Royce Energy Solution Berlin was chosen as the supplier of the system. This system is based on the lithium-ion technology, providing an installed power of 300 kW and a storage capacity of 700 kWh. The system is available for use case application at any time.

3.1.5 Flexible Loads

Heat pumps and Night Storage heaters can partially be leveraged as a source of flexibility, effectively coupling heating and power. Night storage heaters and heat pumps are potential flexibilities preferable used as electrical heat for domestic hot water provision of private customers located in Avacon's electricity network. Flexible Loads owned by households participating in the project will be integrated into the balancing mechanism of the LEC. Active power consumption will be monitored and assets will be activated based on their availability and ability to react to external setpoints defined by the ALF-C. The active involvement will depend on the availability of assets in the field-test region and the success of customer engagement process. Avacon will ensure that the activation of flexible loads will be limited to a level that does not violate the comfort zone of private customers.

3.1.6 Household Batteries

Nowadays, Household Battery Storage Systems are installed in many households in combination with PV systems. The national legislation, defined in the renewable energy act, describes that these storages must not be charged with energy provided by the public grid. This limits the grade of flexibility of these assets, as they can only be activated as a flexible generator, able to ramp up or ramp down the amount of infeed.

3.1.7 Avacon Local Flex Controller (ALF-C)

The Avacon Local Flex Controller (ALF-C) is part of the concept to enable a decentral energy management system of a LEC. The system provides SCADA/ADMS capabilities and functionalities to monitor and forecast generation and consumption. It balances the local grid with access and control of small-scale flexibilities of any type, such as battery storages and flexible loads, in response to violations of technical grid constraints or even external market signals. Within the application of four different use cases, the system will enable following functionalities:

- monitoring of real time total generation and/or demand,
- forecasting of total generation and demand,
- balancing of generation and demand.

Within the Use Cases (UC) the ALF-C uses different Algorithm to

- UC 1 the ALF-C targets to maximise self-consumption of the energy community.
- UC 2 – Maintain a non-zero value defined for the power exchange at the grid connection point
- UC 3 & 4 – enable energy supply and export of generation excess in bulk

The ALF-C will be fully integrated into the Platone Open framework and build a link between the Energy Community EMS and external parties such as DSO, TSO or market players. The ALF-C will provide an interface to the LEC EMS that will enable the synchronization and coordination of flexibility activation with centralised grid management mechanisms of DSOs or TSOs or external flexibility or wholesale markets.

3.2 Definition Power Flows and Signs of Variables

For the description and application of the algorithms used to describe the use cases (see Chapter 5 Use Case Algorithm), a clear and uniform definition of power flows and signs of variables are necessary in order to avoid contradiction. Figure 2 visualises relevant components of the field-test trial and power flows.

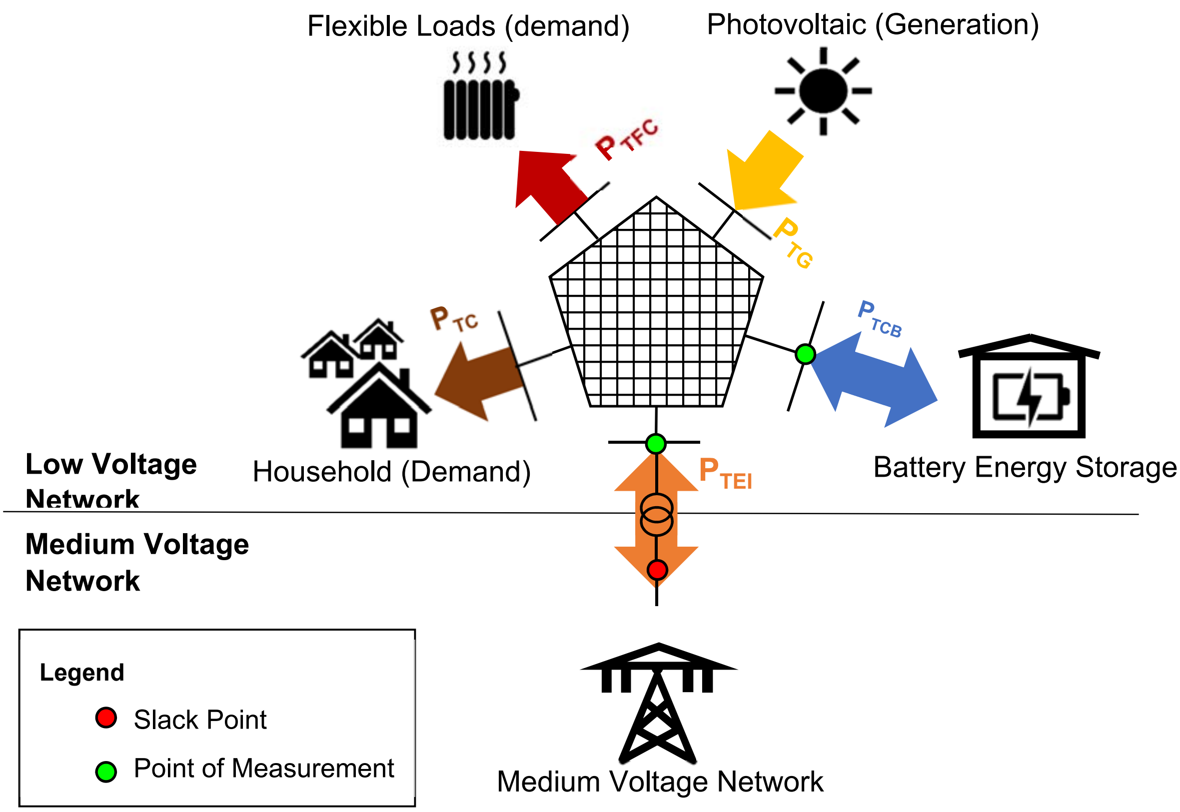

Figure 2: Definition of signs of load flows

The Slack Point, indicated in red, displays the reference point for the definition of positive or negative sign of power flows. Each power flow that directs away from the slack point is indicated with a negative sign and each power flow into the direction of the slack point is indicated with a positive sign.

P_{TEI} – (Total Power Grid Export/Import) rates the active power exchange at the MV/LV grid connection point, connecting the LEC with the MV grid. The value has a positive sign in case of excess of generation or negative in case of generation deficits within the community.

P_{TC} - (Total Household Consumption) rates the active power demand of households and agricultural buildings located in the grid. Since households and agricultural buildings only consume energy, the value always has a negative sign.

P_{TG} – (Total Power Generation from Renewables) indicates the aggregated total active generation power of all PV system located in the field. The value always has a positive sign.

P_{TCB} – (Total Power Charging/Discharging Battery) indicates the aggregated total active power demand or feed of battery storages in the field. The value has a positive sign in case batteries are charging and negative in case of discharging.

P_{TFC} – (Total Flexibility) indicates the aggregated total active power demand of flexible loads. The value always has a negative sign.

Examples

P_{TEI} = -10 kW;	10 kW total power is imported from the MV network into the low voltage network along the grid connection point.
P_{TEI} = 20 kW;	20 kW total power is exported from the low-voltage network into the MV network along the grid connection point.
P_{TC} = - 15 kW	The total consumption of all households of the community (measured) equals 15 kW.
P_{TG} = 50 kW	50 kW of total generation from PV systems is fed into the low-voltage network.
P_{TFG} = -25 kW	The total consumption of all flexible loads (heat pumps and night storage heaters) of the community equals 25 kW.
P_{TCB} = -100 kW	The CBES charge with a total power of 100 kW. The amount of charging energy is equal to the integral of power E_{TCB} (Energy Charging/Discharging) = P_{TCB} * dt.

4 ALF-C IT Architecture

4.1 Overall Architecture

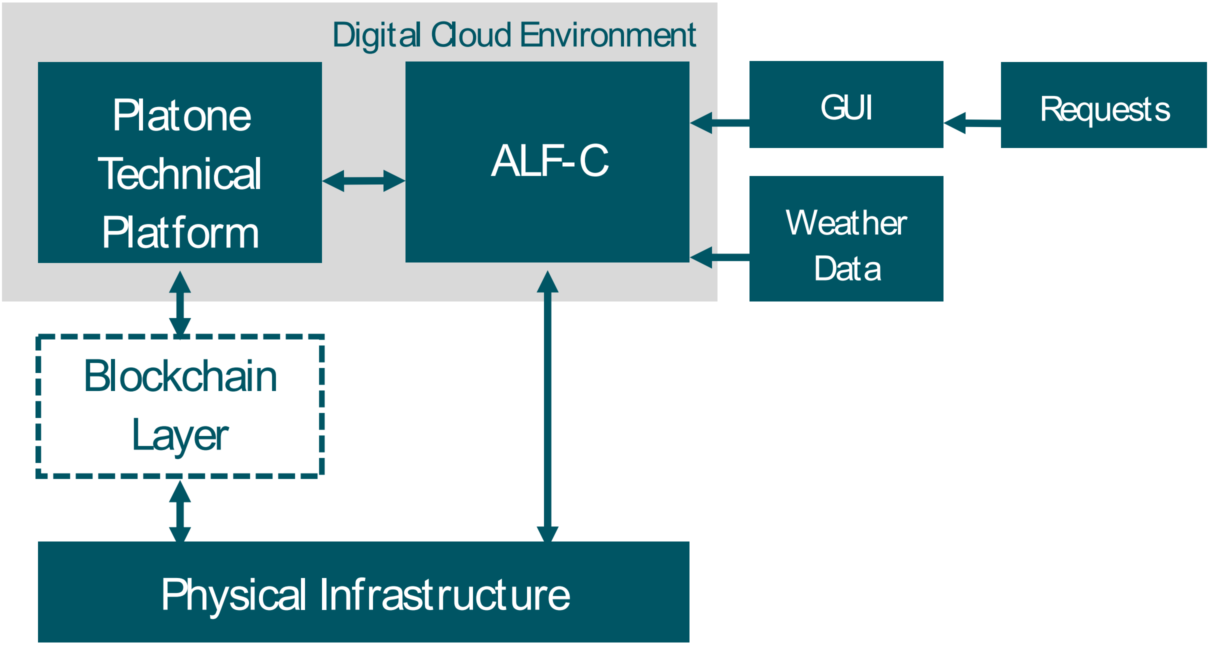

Figure 3: IT Architecture of ALF-C in the Platone framework

Central Grid Control

The central grid control (CGC) is responsible for a safe, reliable and secure operation of the distribution network by making use of a SCADA/ADMS. Grid control provides an estimation of the state of the MV grid based on technical data from voltage and current sensors located in the grid, e.g. in smart secondary substations. Furthermore, it monitors consumption and generation of large-scale assets directly connected to the MV grid, low voltage networks including energy communities and monitors external factors like the weather.

Based on state estimations, the grid control can identify potential imbalances in specific areas of the grid or violations of technical limits, e.g., local voltage excess or current overload of assets (grid congestion). To bring the local grid back to a balanced state and / or to relieve local grid congestion, a cascade of actions can be taken. In case re-balance cannot be achieved by network switching actions, local flexibility will be activated in order to relieve congestion and to return the network to a balanced state. If both these strategies fail, grid control can request a certain amount of power ramp up or ramp down in a specific area of the grid. The ALF-C will then determine the optimal strategy to deliver these actions while keeping total intervention at a minimum and send control commands to achieve the desired outcome.

Control commands will be sent to flexible assets located in the field. In this context LEC are treated as a single source of flexibility aggregated at the grid connection point, whose EMS (e.g. ALF-C) is responsible for the local implementation of commands and adjustment of local flex in order to maintain defined setpoints or setpoint schedules. The role of the CGC will be simulated as part of the use case applications. In this regard, simulated commands will be sent to the ALF-C as setpoint or setpoint schedule by an operator via a user interface.

External Requestors

TSO, DSO or external market agents participating at flexibility or wholesale markets are potential requestors demanding flexibility to be provided by a LEC. In frame of UC 2, flex requests for the provision will be simulated and set by the operator. Requests will be simulated with setpoints defining a fixed value of active power exchange at the MV/LV grid connection of the LEC set by the ALF-C operator.

Operator

The operator triggers the ALF-C to apply use cases, by setting relevant variable via a Graphical User Interface. The operator will simulate request for flexibility provision of the LEC from DSO, TSO, aggregator and market participants.

Weather Data Provider

A weather data service provider delivers weather forecasts for the respected field-test region for 7 days ahead and 4 days past. Data are updated 4 times a day and are provided in hourly increments.

4.2 System Architecture

The ALF-C is a decentral control and dispatch unit that will be implemented in a digital environment, fully integrated within the Platone Open Framework. The system accepts control signals from the grid control centre, processes structural data and data from sensors located in the field, analyses the data and determines switching actions and schedules based on its algorithms. The system is able to aggregate decentral small-scale flexibilities located in the LV grid of the LEC into a single source of flexibility at the grid connection point. The technical architecture is designed in a state-of-the-art modular functional structure that allows high scalability, replicability and portability of the system. Each module is designed as a stateless microservice that provides individual functions but does not process information on the status of other modules. The approach allows to define tasks, interfaces and data transfer for each module clearly and an agile development. Microservices will make use of data and services that will be developed internally or provided as integrated services from different layers of the Platone framework and hosted by the ALF-C.

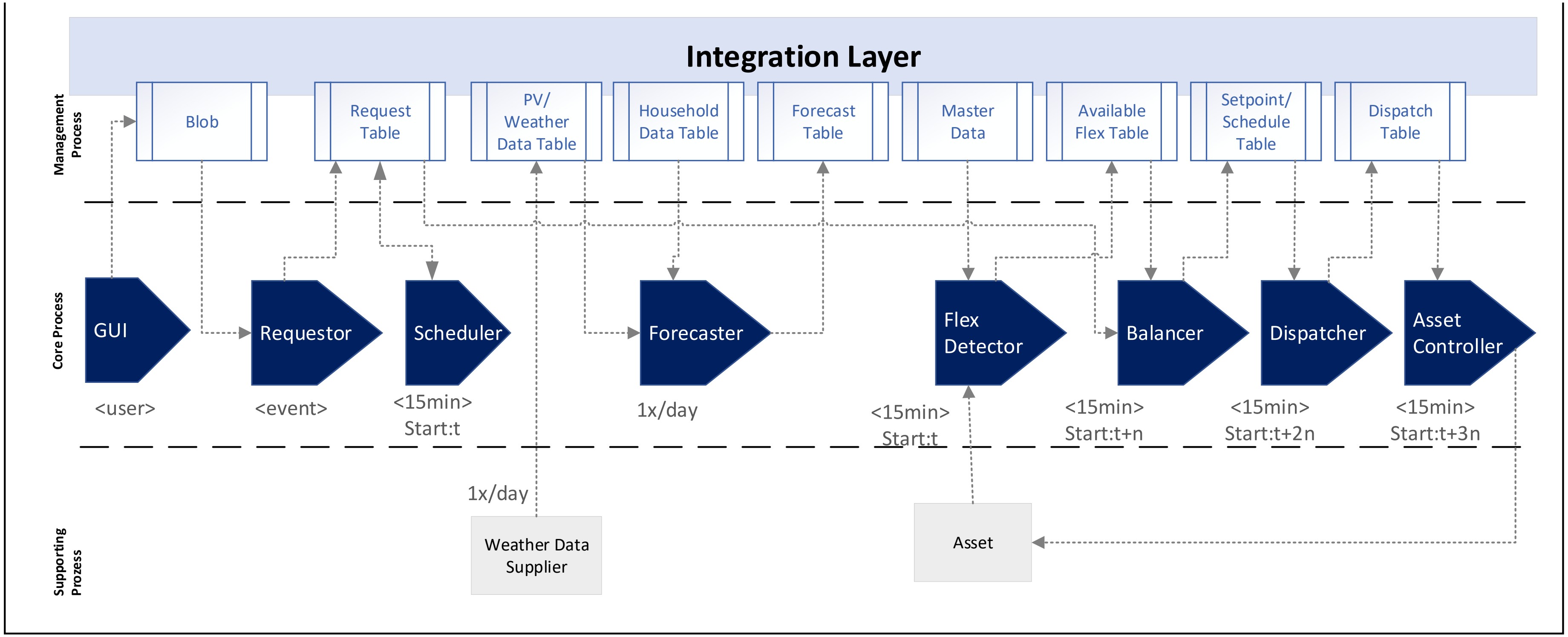

Figure 4: Process Overview of the ALF-C System Architecture

The ALF-C operates in a digital cloud environment. The core process of the ALF-C architecture consists of several modules, shown in Figure 4, that enable the different use cases of the German field-test trial to be performed successfully. The modules run time based and independently. In the integration layer, not only the output of the several modules is stored and accessible centrally but also the data from external service providers such as weather forecast data is centrally accessible. To ensure the realisation of specific use case parameters that can be entered through the GUI, the modules have access to tables and create new tables in the integration layer. The main modules within the ALF-C are Forecaster, Scheduler, Balancer and Dispatcher. The individual modules of the ALF-C are described in the following subsections.

4.3 Graphical User Interface (GUI)

The GUI is the web-based graphical user interface in which the use case for the field-test trial can be selected by the operator. Additional parameters can be adjusted. After sending the request to the ALF-C, a Binary Large OBject (blob) file will be created and stored in the Integration Layer. The Requestor will check for new blob files. When a new blob file is detected, the Requestor will transform the information into a table and save it in the request table, which lies in the integration layer and will automatically be put as blob file into the archive. A traffic light (green, yellow, red) on the GUI shows the actual state of the ALF-C to the operator. If the green light lights up after sending the request, it means that the request has been sent to the ALF-C successfully and will most likely be executed next. The yellow light gives the operator the signal that there is already a request running. Here, the operator does not know how the sent request will be prioritised. The red light can be interpreted as an error. If more information about the sent request is required, a viewer can be used to look at the status of all sent requests in the integration layer.

The GUI will enable the UC-operator to set the UC and relevant variables. The Table 4 gives an overview of different variables to be set via the GUI.

Table 4: GUI Data Input and Output

Variable	Content
UC	Use Case
$t_{UC; Start}$; $t_{UC; End}$	Point of time of start/end of Use Case
SOC_{Start}; SOC_{End}	State of Charge of Local Battery Energy Storage (LBES) at start/end of Use Case
$t_{SOC Start}$; $t_{SOC End}$	Point of time of start/end of LBES charging/discharging in order to reach SOC_{Start}; SOC_{End} at $t_{UC; Start}$; $t_{UC; End}$
Priority*	Defines the priority of the request for flex activation over flex request of other requests

* in case of UC 2

4.4 Scheduler

The Scheduler module is responsible for the coordination of requests. This module sets the time and prioritisation of the incoming demands. Flex provision demands (UC 2) are always more highly prioritised than all other demands. The Scheduler is able to overwrite the status of the requests in the request table. It activates the demands, put them on hold, break them and gives back error in case the demand cannot be processed. Defined status types are new, active, on hold, break, and error.

Table 5: Scheduler Data Input and Output

Value	Input/Output	Unit	From
Use Case Type	Input	n.A.	GUI (Operator)
Use Case Start/End – $t_{UC, Start}$ $t_{UC, End}$	Input	n.A.	GUI (Operator)
UC 3 / 4 - Window 1 Start/End - $t_{W1; Start}$, $t_{W1; Start}$	Input	Time	GUI (Operator)
UC 3 / 4 - Window 2 Start/End - $t_{W2; Start}$, $t_{W2; Start}$	Input	Time	GUI (Operator)
Priority	Input		GUI (Operator)
UC Point of time of Use Case Setting – $t_{UC, trigger}$	Output	time	GUI (Operator)

4.5 Forecasting Module

The Forecast module continuously generates forecasts of total generation (PF, TG), total consumption (PF, TC) and the residual load demand (PF, TEI) of the aggregated flexibilities of the LEC at the MV/LV grid connection point for up to 48 hours ahead based on weather forecast and historic measurement data. Input data and calculation results are made available or read out via an interface with the integration module. Forecasts will be based on weather forecasts provided by an external service.

The Forecasting Module will be implemented in two steps: the static forecast and the dynamic forecast.

4.5.1 Static Forecast

The static forecast consists of two forecast qualities that generate the load forecast using a standard load profile.

Forecast Quality 1

The consumption forecast is made by scaling the standard load profile to Abbenhausen (power / annual consumption). The value from the same day in the previous year or possibly the last week is used for the forecast.

The feed-in forecast is determined using a weather forecast. A service provider provides a forecast of the PV generation "PV-Pro", which describes the generation output of a reference system. The value made available will be put into relation of installed PV power in order to determine the total generation.

Forecast Quality 2

The forecast of consumption and feed-in is carried out as in Forecast Quality 1. Additionally, historical data from the intelligent sub-grid station is processed. Historical forecasts are compared with the actual measurements and a correction factor is determined. This correction factor is considered when forecasting consumption and generation.

Table 6: Forecast Module Data Input and Output

Value	Input/Output	Unit	Data Interval	Interval of Update
	Weather Forecasts			
PV Generation	Input	$kW_{Generation}$ / $kW_{Installed\ Capacity}$	1 h	6 h
Solar Radiation (GHI, GNI, DIF)	Input	W/m²	1 h	6 h
Cloud Cover	Input	%	1 h	6 h
Temperature	Input	°C	1 h	6 h
Windspeed	Input	km/h	1 h	6 h
Forecast of Total Generation - P_{TG} (t + 24h)	Output	kW	15 Minutes	-
Forecast of Total Consumption - P_{TC} (t + 24h)	Output	kW	15 Minutes	-
Forecast Residual Lead Demand - P_{TEI} (t + 24h)	Output	kW	15 Minutes	-

4.5.2 Dynamic Forecast

The dynamic forecast is carried out using machine learning. Historical and forecasted weather data are made available by a service provider (packages “Solar”, “Sunmoon”, “Basic”, History Clouds, History Solar). The forecast of the power exchange at the grid connection point is determined with an algorithm that uses historical measured power flow data, measured weather data (e.g. local weather station) and provided weather forecasts as input values.

Forecast Quality 3

The forecast of generation and consumption is based on historical power flow measurement data, which are recorded at the local substation (P_{TEI}). With the use of weather forecast, historical measured values can be accessed that are based on a similar weather profile.

4.6 Balancing Module

The Balance module determines the aggregated amount of flexibility (P_F) to be activated in order to balance consumption and generation within the local grid in such the way that the power exchange at the grid connection point (P_{TEI}) equals a target value P'_{TEI} (i.e. $P_{TEI} = P'_{TEI}$). The balancing mechanism will be implemented in two stages based on different concepts.

Measurement & Control Cycle

The balancing algorithm is based on a real time measurement of the load exchange at the grid connection point (P_{TEI}). In case of deviation of $\Delta P = P_{TEI} - P'_{TEI} \neq 0$, consumption or feed of flexible assets will be ramped up or ramped down.

The mechanism will be applied within a first approach of Use Case 1– Virtual Islanding (Step 0) and Use Case 2.

$$P_{TFD} = (-1) * (P_{TEI} - P'_{TEI})$$

Schedule Based Control

The schedule control approach will be applied is Use Case 1 Step 1, Use Case 3 and 4 in case. The approach uses as input data forecasts of for hours ahead $P_{F;TEI}$ (t+48h) determined by Forecast module available energy for feed in to the grid E_{F+}, available unused storage capacity E_{F-}, maximum available power for feed (P_{F-}) and available maximum power for charge (P_{+}). The Balancing Module proves whether available flexibility is sufficient to compensate forecasted generation surplus or load deficits.

Case 1 – In case sufficient storage capacity and load is available to compensate forecasted generation surplus or load deficits, then:

$$P_{TFD}\ (t+24h) = (-1) * P_{F,TEI}\ (t+24h)$$

Case 2 - In case available storage capacity and load are not sufficient to compensate forecasted generation surplus or load deficits, then an algorithm based on an optimization will be applied to determine P'_{TEI} to make maximum use of available flexibility and storage capacity and minimise the load exchange at the grid connection point. The logic of the algorithm is described in detail in sections 5.1.2, 5.3 and 5.4.

Table 7 gives an overview of variables as input and output of the balancing module.

Table 7: Balancing Data Input and Output

Value	Input/Output	From	To
Use Case Type	Input	Scheduler	
Forecast - $P_{F,\ TEI}$ (t+24h)	Input	Forecaster	
Use Case Start/End – $t_{UC,\ Start}$ $t_{UC,\ End}$	Input	ALF-C Core Module	
UC 3 / 4 - Window 1 Start/End - $t_{W1;\ Start}$, $t_{W1;\ Start}$	Input	ALF-C Core Module	
UC 3 / 4 - Window 2 Start/End - $t_{W2;\ Start}$, $t_{W2;\ Start}$	Input	ALF-C Core Module	
Available Storage Capacity - E_F (T_i)	Input	Dispatcher	
Available Power - P_F (T_i)	Input	Dispatcher	
Aggregated Flexibility Activation P_{TFD} (t) or P_{TFD} (t+24)	Output		Dispatching Module

4.7 Dispatching Module

The Dispatching module consists of a Flex Detector and a Dispatcher component. The module is linked to the Balancer module and Asset Control module. The module is responsible for the acquisition of flexibility and determination of amount of available flexibility, reporting available aggregated flexibility and dispatches aggregated request for flexibility activation request set by the balancing into individual setpoint for flexible assets located in the grid.

1.) Flexibility Acquisition (Flex Detector)

Each flexible load, household storage or community storage will be monitored by the Flex Detector of the Dispatcher module. The module communicates with the flexible assets in the field and receives ($SOC_{F,I}$) of energy storages and available power for ramp up or ramp down ($P_{F,I,}$).

2.) Aggregation of available flexibility (Flex Detector)

Based on data provided by individual flexible assets the module determines the aggregated total value of available power ($P_{T,F,A} = \sum P_{F,A;1}; P_{F,A;2}; \ldots\ldots; P_{F,A;N}$) for 24 hours ahead, aggregated total value of available storage capacity ($E_F = \sum E_{F,1}; E_{F,2}; \ldots; E_{F,N}$) for 24 hours ahead based on SOC of individual assets.

3.) Dispatching of aggregated flexibility activation (Dispatcher)

The module receives aggregated flex requests determined by the Balancer module $P_{TFD}(t)$ and disaggregates it into individual setpoint $P'_{F,A}(t)$ for flexible assets.

Table 8: Dispatching Module Data Input and Output

Value	Input/Output	Unit	From	To
Minimum State of Charge $SOC^{i}_{F;MIN}$	Minimum state of charge	%	Base Data Module	-
Maximum state of charge $SOC^{i}_{F;MAX}$	Minimum state of charge	%	Base Data Module	-
Measured real time State of Charge $SOC^{i}_{F;Real}$	Input	%	Flexible Assets	
Nominal power of asset P^{i}_{N}	Input	kW	Base Data Module	
Nominal storage capacity of asset E^{i}_{N}	Input	kWh	Base Data Module	
Measured power of feed/demand * $P^{i}_{Measured}$	Input	kW	Flexible Assets	
Aggregated Available Storage Capacity (+/-) E^{i}_{F+} - E^{i}_{F-}	Output	kWh	-	Balancer

Aggregated Available Power (+/-) $P^i_{F,A,+}$ $P^i_{F,A,-}$	Output	kW	-	Balancer
P_F(t)	Input	kW	Balancer	
$P^i_{F;S}$ (t)	Output	kW		Asset

5 Use Case Algorithm – Narrative Description

The following section describes in detail for each UC the algorithm logic and steps in order to implement use case targets. The algorithm of each use case integrates different modules and components of the ALF-C. The modules provide functionalities based on individual algorithm developed and provided by RWTH Aachen along the DSO Technical Platform, developed and implemented by Avacon or provided as logic apps by Microsoft (MS) Azure. The workflow of the use case algorithm is scheduled in Figure 5. The use case workflow chart illustrates the interaction with the ALF-C for a certain selected use case from the point of view of the user. In the total process from start to end, this graphic illustrates the deviation in the workflow for the different use cases. For example, for Use Case 1 Step 0 and Use Case 2 basically the measurement and steering cycle is used. The Balancer module determines single setpoints as outcome. For Use Case 1 Step 1, Use Case 3 and Use Case 4 a forecasting is included and the Balancer module determines aggregated setpoint schedules for activation of flexibilities.

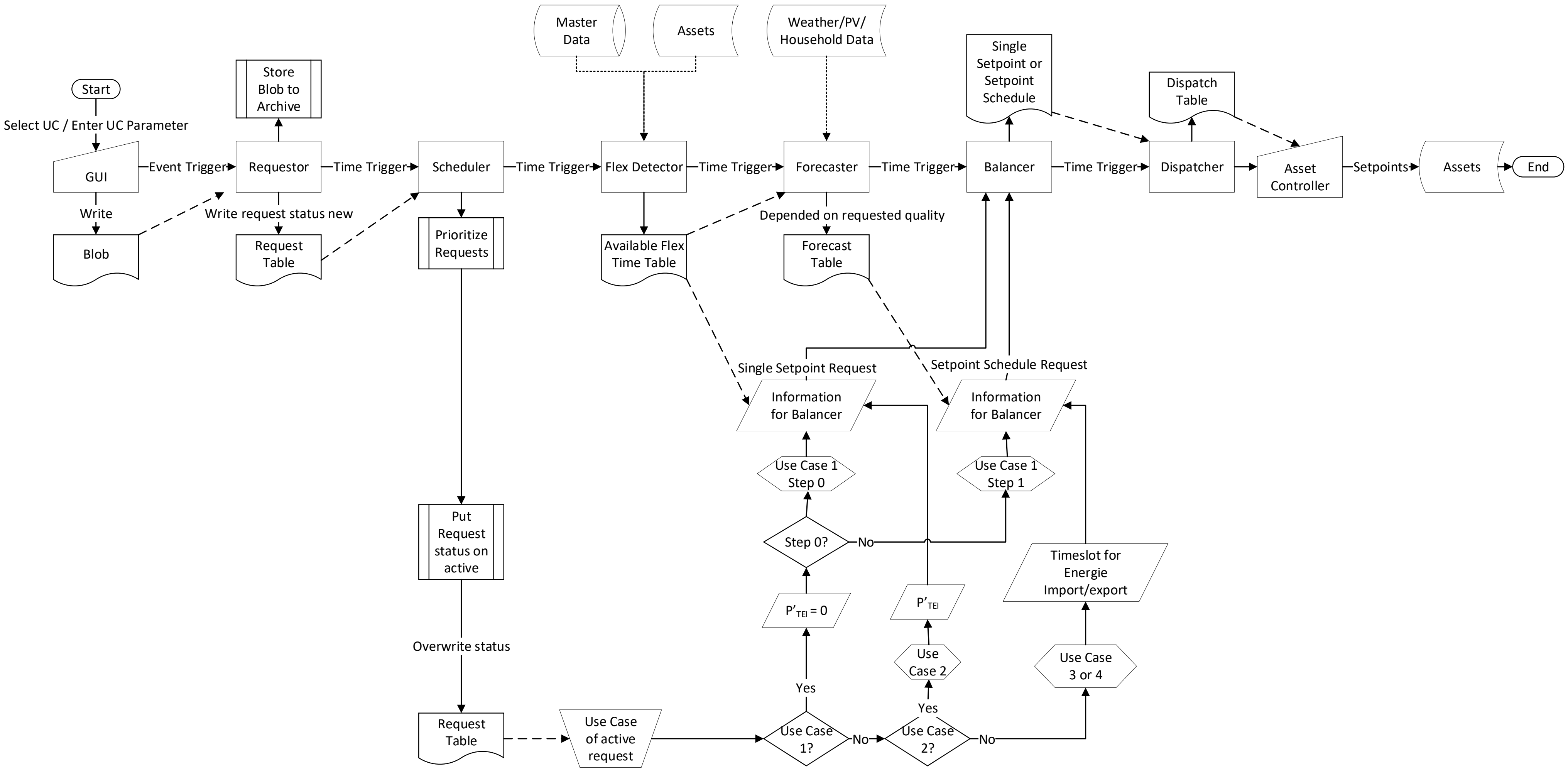

Figure 5: Use Case Algorithm Flowchart

5.1 Use Case 1 Algorithm – Islanding

The aim of this use case is to enable a LV grid section or LEC to maximise consumption of local generation up to a level at which the load exchange at LV/MV grid connection point is close to zero. In the following, the UC algorithm steps are described in detail.

5.1.1 Use Case Trigger

- Operator sets UC 1 variables via GUI
- Setting of Use Case Type = 1
- Setting of point of time of Islanding Execution Start $t_{IE,\ Start}$ and Islanding End $t_{IE,\ End}$

5.1.2 Forecasting

The Forecaster module predicts the residual load exchange $P_{F,TEI}$ for the next 24 hours based on a forecast of total generation $P_{F,\ TG}$ and total consumption $P_{F,\ TC}$. An example is displayed in Figure 5. Depending on the status of implementation and development of the ALF-C different stages of forecast will be applied. The different stages and input variables are described in section 4.5. The applied algorithm is detailed in section 6.3.

5.1.3 Determination of Available Flex and Status of the grid

Before the Use Case the Dispatcher module (Flex Detector) determines the aggregated amount of available energy for charge $E^i_{F,A,+}$, the stored energy available for discharge $E^i_{F,A,+}$, the maximum amount of power in the positive direction $P^i_{F,A,+}$ and in the negative direction $P^i_{F,A,-}$. For the determination of number of available flexible assets, the Flex Detector applies the algorithm displayed in section 6.5.1. Algorithm Input data will be collected from relevant assets $i \in \mathcal{N}$, where $\mathcal{N}$ is the set of all available flexibilities, and base data from base master storage ($SOC^i_{F;MIN}$, $SOC^i_{F;MAX}$) and real time measured data from assets in the field ($SOC^i_{F;Real}$, P^i_{Real}). Further, the real time load exchange at the grid connection point P_{TEI} will be determined.

5.1.4 Balancing

With UC 1 the target of the Balancer module is to avoid or minimise a load exchange $P'_{TEI} = 0$ at the grid connection point within the Islanding period T_i $t_{IE,\ Start,\ End}$ to $t_{IE,\ End}$ and maximise consumption of locally generated energy. In case the available flexibility $E^i_{F,A,+}$; $E^i_{F,A,+}$; $P^i_{F,A,+}$ and $P^i_{F,A,-}$ is not sufficient to compensate imbalances during the period T_i , the load exchange will be minimised.

The balancing mechanism of use case will be implemented in two steps:

I. Measurement- and Control Cycle

II. Schedule Based Approach

1) Real Time Measurement- and Control Cycle

The measurement and control cycle is based on a real time balancing approach in which the delta DP = P_{TEI} - P'_{TEI} is monitored and determined in 15 minutes steps. In case I, $\Delta PI \neq 0$, then the required activation of flexibility P_F(t) will be calculated with $P_F(t) = (-1) * \Delta P$ in order the achieve P_{TEI} - P'_{TEI}.

Within each cycle the balancing algorithm proves whether required adaptions of P_F and $E_F = P_F * Dt$ (Dt = 15 Minutes) can be implemented by available flexibility $E^i_{F,A,+}$, $E^i_{F,A,+}$, $P^i_{F,A,+}$ and $P^i_{F,A,-}$. if this is the case, P_F will be dispatched into individual setpoint for available assets by the Dispatcher module. The applied algorithm is displayed in section 6.4.1.

2) Schedule-Based Approach

The schedule-based approach does not foresee a real time measurement and control cycle. It is based on a preliminary forecast of imbalances and determination of a schedule for activation of flexibility to achieve the target $P_{TEI} =! 0 = P_{TCB} + P_{TG} + P_{TC}$. The applied algorithm is described in section 6.4.2. Based on the determined schedule flexibilities will be activated without subsequent changes during the period T_i.

Step 1 - Based on forecast data the Balancer module determines:

- the time periods in which generation > consumption and periods in which generation < consumption including the point of time of period start and end ($t_{Surplus,\ Start}$, $t_{Surplus,\ End}$,$t_{Deficit,\ Start}$, $t_{Deficit,\ End}$),
- the generated energy surplus (E_{GS}) within the period from $t_{Surplus,\ Start}$ to $t_{Surplus,\ End}$ and energy deficits (E_{GD}) within the period from $t_{Deficit,\ Start}$ to $t_{Deficit,\ End}$.
- the total peak values ($P_{F,\ TEI,\ Peak}$) import or export and
- the amount of power $P_{Total\ Flex}$ necessary to gain $P_{TEI} = P'_{TEI}$.

An exemplary forecast for a 48-hour period, determined values and available flexibility are visualised in Figure 7.

Step 2 – The algorithm compares $P_{F,\ TEI,\ Peak}$, E_{GS}, E_{GD} with $E^i_{F,A,+}, E^i_{F,A,+}, P^i_{F,A,+}$ and $P^i_{F,A,-}$ to determine whether imbalances can be compensated by available flexibility.

Case 1 - Sufficient availability of flexibility

The amount of available flexibility is sufficient to compensate imbalances during the period T_i in order to gain $P_{TEI} = P'_{TEI} = 0$.

In this case, the schedule for activation of flexibility will be determined by applying the formula:

$$P_{TFD}\ (t+24h) = (-1) * P_{F,\ TEI}\ (t + 24h)$$

$$P_{TFD}\ (t + 24h)\ =\ (-1)\ *\ PF;\ TEI\ (t + 24h)$$

Case 2 – Not sufficient availability of flexibility

The available amount of energy is not sufficient to compensate imbalances. During the period $P_{TEI} = P'_{TEI} = 0$ cannot be achieved at all times. In this case, the following targets and restriction have to be respected:

1.) The consumption of local generation shall be maximised,
2.) During the Use Case period T_I the load exchange shall be minimised;
3.) Available flexible load (P_F) and storage capacity shall be fully used test:

Applying the rules to the example shown would lead to a reduction of energy export during periods of generation surplus. Available batteries will be charged and later discharged during times of generation deficits. This way deficits will be compensated. At the end of the period Ti, the SOC of batteries will be higher compared to the initial SOC at the beginning of the UC. In order to determine the aggregated setpoint schedule for the activation of flexibility the balancing algorithm applies an optimization that enables the maximization of consumption of local generated energy and minimise the load exchange along the grid connection point $P_{TEI,Peak}$ within period Ti . Starting from the point $P_{F,\ TEI,\ PEAK}$ at the point of time t, $P_{F,\ TEI,\ PEAK}$ will be minimised ($P_{F,\ TEI,\ PEAK} \rightarrow P'_{F,\ TEI,\ PEAK}$) until:

1.) $\int_{t,F,Start,A}^{t,F,End,A} P_{F,TEI}$ (dt) equals the available storage capacity $E_{F,\ A}$. or

2.) $\triangle P = P_{F,\ TEI,\ Peak} - P'_{F,\ TEI,\ Peak} = P^i_{F,A,-}$

The logical approach is visualised in Figure 7. As show in the figure, starting from the yellow indicated ($P_{F,\ TEI,\ PEAK}$) the yellow dashed line will be shifted stepwise (15-Minutes Intervals along x-axis) down the y-axis. The red indicated area $+B1$ will rise with each step of shifting. The area will be increased until $+B1$ equals E_F, meaning the curtailed amount of energy equals available storage capacity. This is the case at the red dashed line. The optimum starting point and the end point for the activation of flexibility can be determined at the point at which the red dashed lines cross the forecast curve

($t_{F,\,Start,\,A}$; $t_{F,\,End,\,A}$). In the next step the schedule for the activation of flexibility can be calculated by applying following formula:

$$P_{F,TEI,Peak}: [t_{F,\,Start,\,A};\, t_{F,\,End,\,A}] \rightarrow [-\infty, 0]$$

$$P_F\,(t+24h) = ((-1) * P_{F,TEI}(\mathrm{t}+24\mathrm{h}) - P'_{F,TEI,Peak}(\mathrm{t}+24\mathrm{h})$$

Figure 8 shows the result of the optimization, indicating with a red coloured area named $B+$ the amount of energy that will be generated as surplus and stored in local battery storages within the period from $t_{Surplus,\,Start}$ to $t_{Surplus,\,End}$. The energy ($B+$) stored has to be fully discharged ($B-$) into the grid within the period of time from $t_{Deficit,\,Start}$ to $t_{Deficit,\,End}$ in which total consumption is higher than generation ($P_{TC} > P_{TG}$). The red graph indicates the schedule of activation of flexibility. The total value of aggregated power to be provided by the available flexible assets $P_{TFD}\,(t)$ is determined by

$$P_{TFD}\,(t) = P_{F;\,TEI}\,(t_{\,F,\,Start,\,B};\, t_{\,F,\,Start,\,E}) - (P'_{F;\,TEI;\,Peak})$$

5.1.5 Execution (Dispatching)

The schedule of $P_{TFD}\,(t)$ determined by the Balancer module will be disaggregated into individual setpoints for available flexible assets in the LEC and dispatched by the Dispatcher module. Figure 7 shows the result of the optimization. It shows that the peak value of the absolute amount of $|P_{F,\,TEI,\,Peak}|$ will be decreased to $P'_{F\,TEI,\,Peak}$. The resulting power flow at the LV/MV grid connection point is indicated in Figure 8. The applied algorithm is displayed in section 6.5.2.

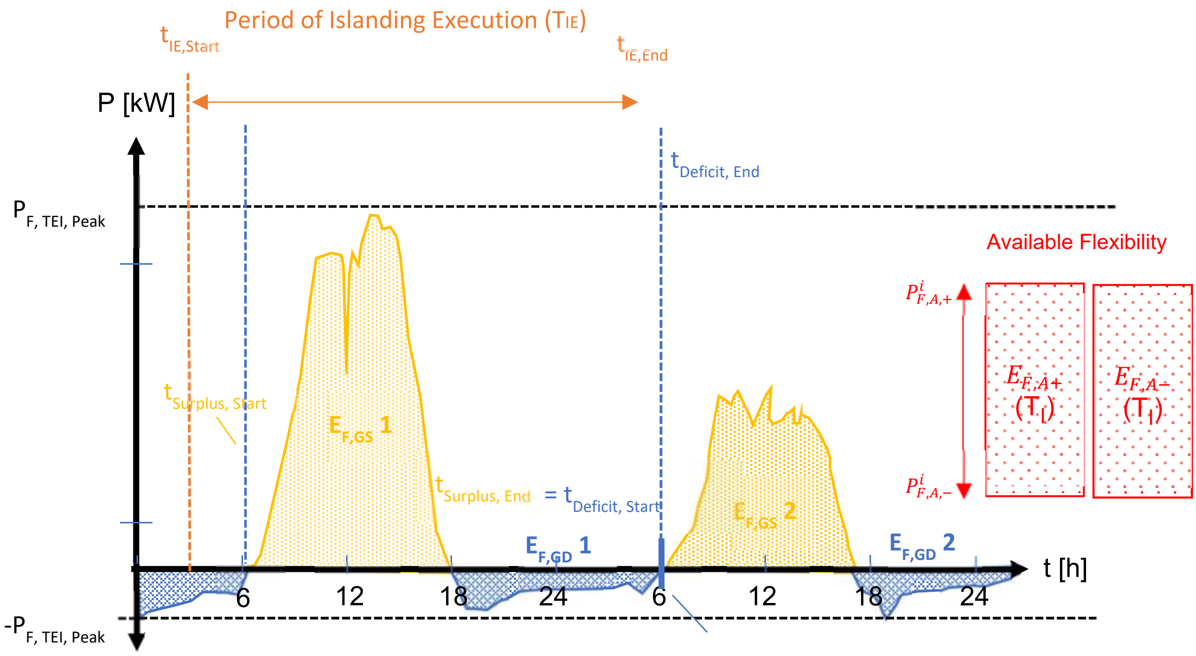

Figure 6: Forecasted load profile at the grid connection point for 48h

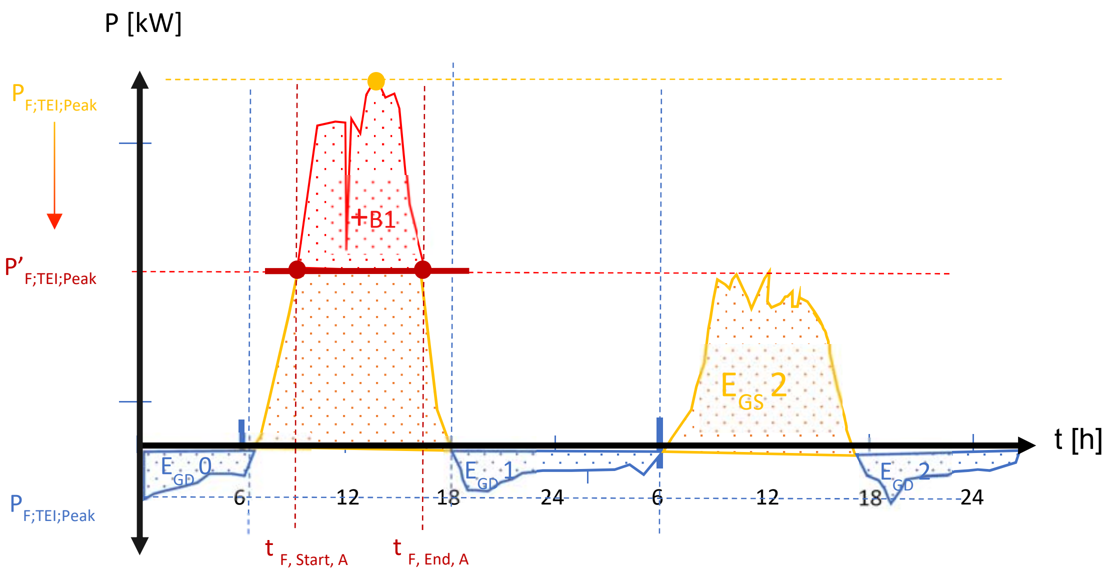

Figure 7: Result of the optimization of the load profile by using the CBES

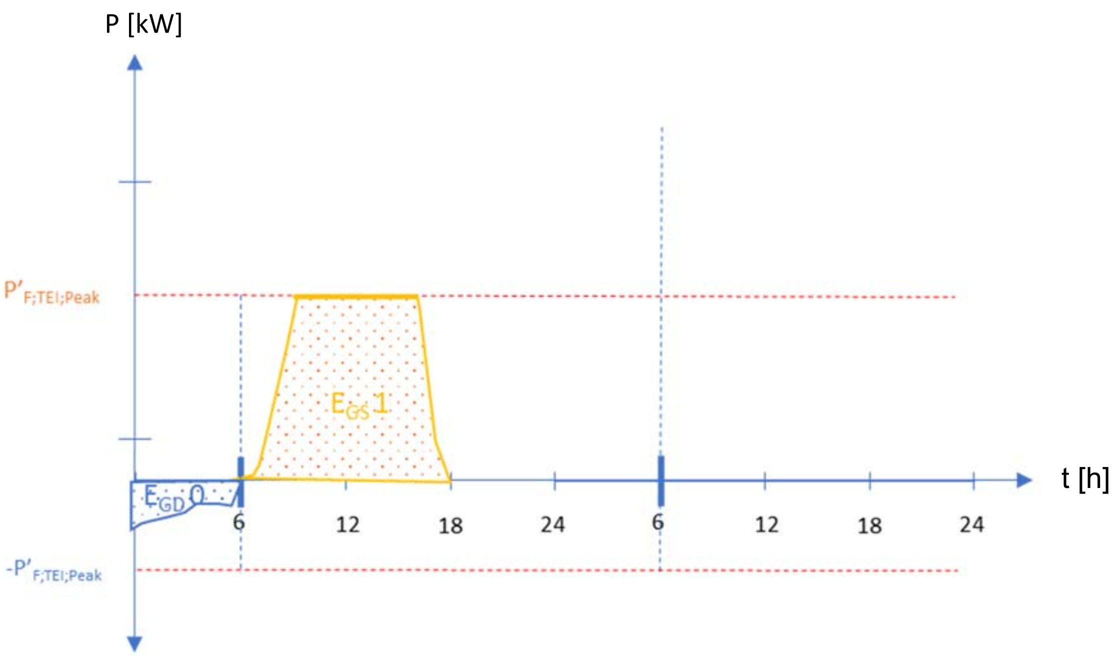

Figure 8: Load profile at the grid connection point after using optimization

5.2 Use Case 2 – Flexibility Provision

Use Case 2 focuses on the coordination of flexibility request send from external third parties (operator) and its execution. Further the ALF-C shall aggregate flexible assets to a single source of flexibility and balance the grid in such a way that a non-zero value of power exchange at the LV/MV grid connection point will be maintained.

5.2.1 Coordination of Flex Request from Third Parties

The request for the provision of active power can result from market activities on flexibility markets, DSO or TSO, for grid stabilizing purposes and solving of bottlenecks. Aggregators can request power in order to manage balancing groups, whereas LEC tries to maximise to maximise self-consumption over time. The inquiries for flexibility of different actors can overlap in time and differ in priority, depending on the purpose of the use of flexibility. A simultaneous execution of the requests by the ALF-C is not possible. In order to coordinate the execution, requests have to be prioritised. According to the prioritisation of the requests, the ALF-C in the context of the UC 2 always only executes the request with the highest priority within the scope of the available flexibilities.

As a consequence, each request must be given a prioritisation. The priority ranking logic of requests will be based on the traffic light concept that has been defined by the German Federal Association for Energy and Water Management (BDEW) [7]. As listed in the Table 9 this concept describes 3 different priorities for the activation of flexibilities in the electricity grid based on the purpose of use. For the UC 2 implementation and prioritisation of flex request, the concept has been extended by a fourth value of priority for future LEC targeting to apply UC 1.

Table 9: Definition of Prioritisation of flex request

Priority	Requestor	Content	BDEW-Traffic Light
1 – Highest Priority	DSO, TSO	Flexible power is needed to solve real time congestions leading to exceeding technical limits and overload of network equipment.	Red Phase
2 – Medium Priority	DSO, TSO, Marked	Congestions in the network will be forecasted by DSO or TSO and will be solved with the procurement of flexibilities via market actions and contraction for flexibility provision. Interactions take place between SO and market participants.	Yellow
3 – Low Priority	Marked	Flexibility request that are not intended to solve critical grid status. Markets are allowed to trade and activate system or market relevant flexible assets to contribution to the integration of fluctuating feed-in or demand.	Green
4 – Very Low Priority	Community	Flexibility is not requested to sole critical grid status and the community is not participating on wholesale or flexibility market. The LEC targets to maximise self-sufficiency and maximise consumption of locally generated energy.	White

The logic of prioritisation will be implemented within the use case algorithm of UC 2. In case inquiries from different parties, e.g., DSO, TSO or energy market, have the same priority and a time overlap, then the request will be scheduled with a second level priority based on the time stamp of receiving of the request.

Figure 9 gives an example of flexibility request from different parties with different priorities. The figure shows along the time the point of time at which the request has been received. Figure 10 shows the resulting total value of power exchange at the grid connection point as result prioritisation and coordination of activation of different requests.

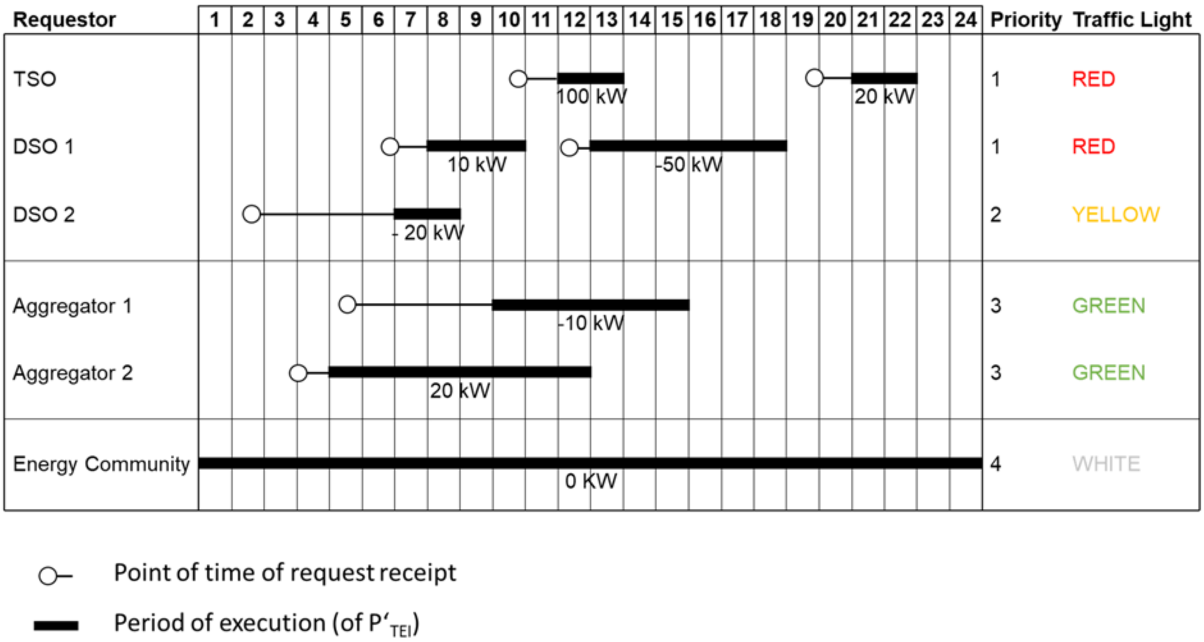

Figure 9: Use Case 2 Algorithm - Example Flexibility Request from Third Parties

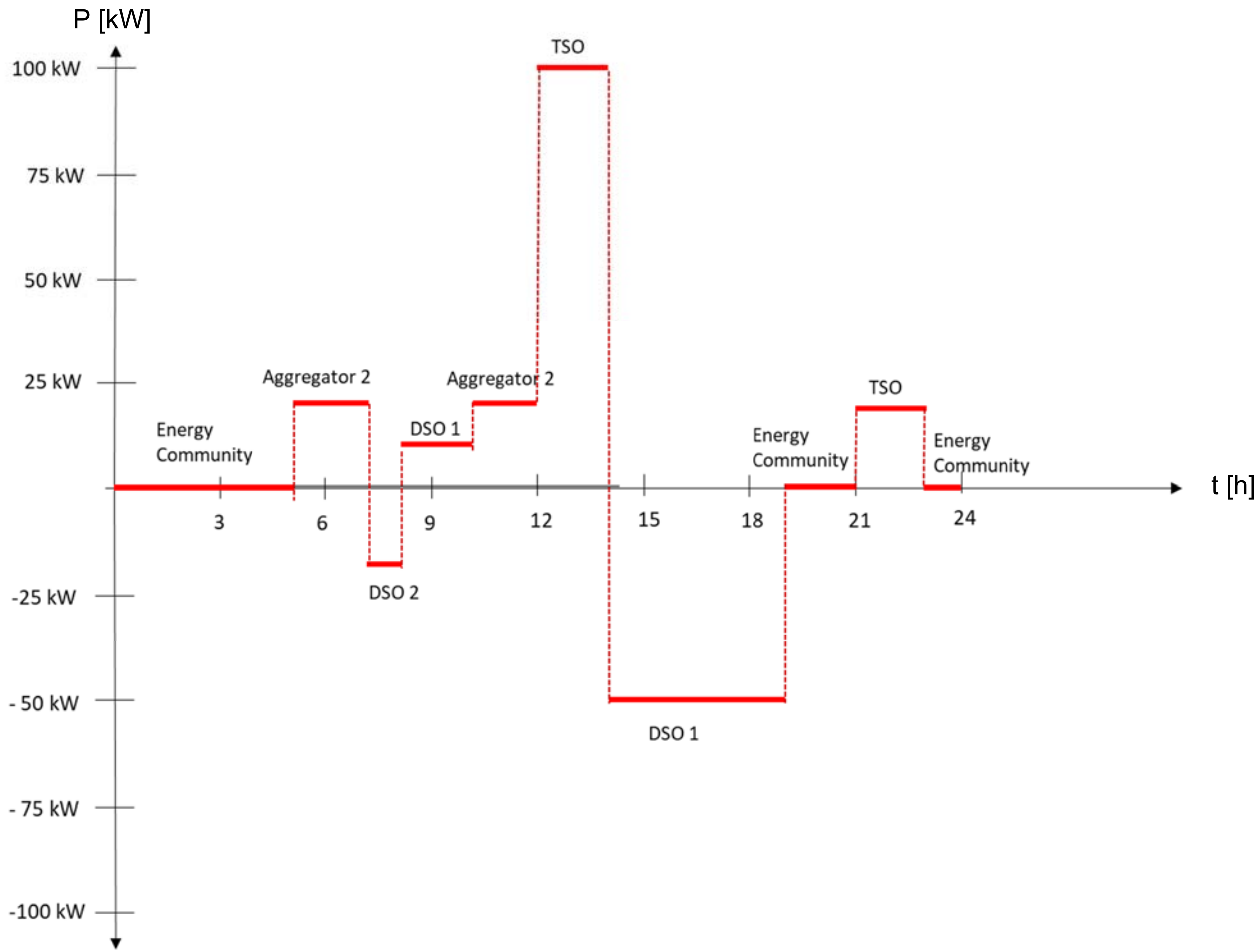

Figure 10: Use Case 2 Algorithm Logic - Example of Load Demand Schedule for Execution

5.2.2 Use Case Scheduling

The Scheduler will be the central component enabling the synchronization of local flexibility activation with requests sent from centralised grid management instances or markets. Based on the request data set via GUI, the Scheduler will prioritise the flexibility activation based on priority of the request (BDEW traffic light concept) and the timestamp of all requests. In the next step, the Scheduler will determine a consolidated target schedule (P'_{TEI}) to be further processed by Balancer module and executed by the Dispatcher. The Scheduler will be implemented via Logic and Function Apps provided by MS Azure running functions developed in Python.

5.2.3 Balancing and Execution

Based on an real time measurement control cycle as described in section 5.1.4 – 1, the ALF-C will determine the aggregated setpoint of flexibility activation (P_F) in order to change the load exchange at the LV/MV grid connection point. For this purpose, the balancing algorithm step 0 will be applied. The applied algorithm is displayed in section 6.4.3.

5.3 Use Case 3 – Bulk Energy Import

Within UC 3 a new concept of energy supply shall be investigated and tested contributing to relieving MV and HV grids of additional stresses caused by LV grid load peaks. The aim is to enable the ALF-C to change the way of energy consumption of LV grids or LECs from the paradigm of real-time supply to a time-shifted supply by making use of local flexibilities. UC 3 focuses on load-driven grids. The energy demand shall be forecasted and imported in a bulk in advance and buffered in local storages for later use. The suitable time for the import shall be set by the CGC, whereas the ALF-C determines the appropriate amount of energy in order to minimise the load exchange and maximise consumption of locally generated energy outside the set time window for energy import.

1.) Use Case Trigger

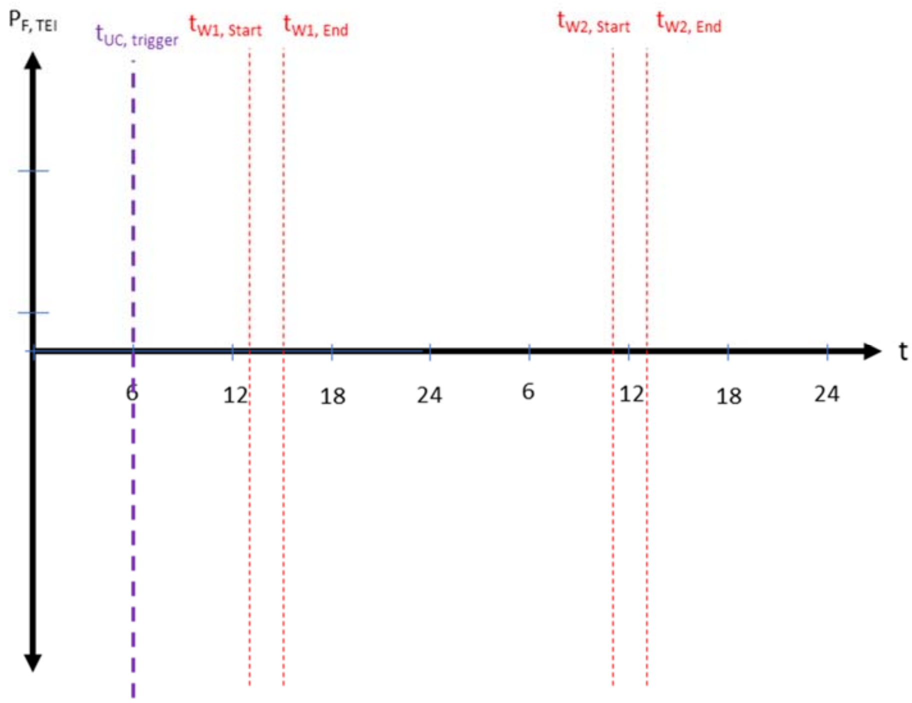

Figure 11: Use Case 3 Algorithm Logic - Example - Time Slot for Energy Import

The Use Case starts with a trigger set by an operator via a GUI at the point of time $t_{UC;\,trigger}$. The CGC determines time slots for the power exchange at the LV/MV grid connection point for at least 48h ahead. For each day one timeslot will be defined. Time slots may be set for different points in time and for different durations from day to day. Figure 11 visualises an example at which on day 1 a time window is set with a starting point ($t_{W1,\,Start}$) at 1:00 pm and an end point ($t_{W1,\,End}$) at 3 pm. For day 2 $t_{W2,\,Start}$ = 11 am and $t_{W2,\,Start}$ = 1 pm.

2.) Forecast

The total generation and demand and the resulting load exchange at the LV/MV grid connection point will be forecasted for 24 hours ahead ($P_{F;\,TEI}\,(t{+}24h)$) based on a forecast of total generation $P_{F;\,TG}\,(t{+}24h)$ and total consumption $P_{F;\,TC}\,(t{+}24h)$. The forecast will be determined for the Islanding Period $T_{IE} = \Delta t$ with the point of time $t_{IE,\,Start}$ until $t_{IE,\,End}$. The algorithm applied is displayed in section 6.3.

Figure 12 shows the schedule for a forecasted residual power exchange along the grid connection after generation and consumption $P_{F;\,TEI}$ for a period of 48 hours. The area under the curve displays the exchanged amount of energy.

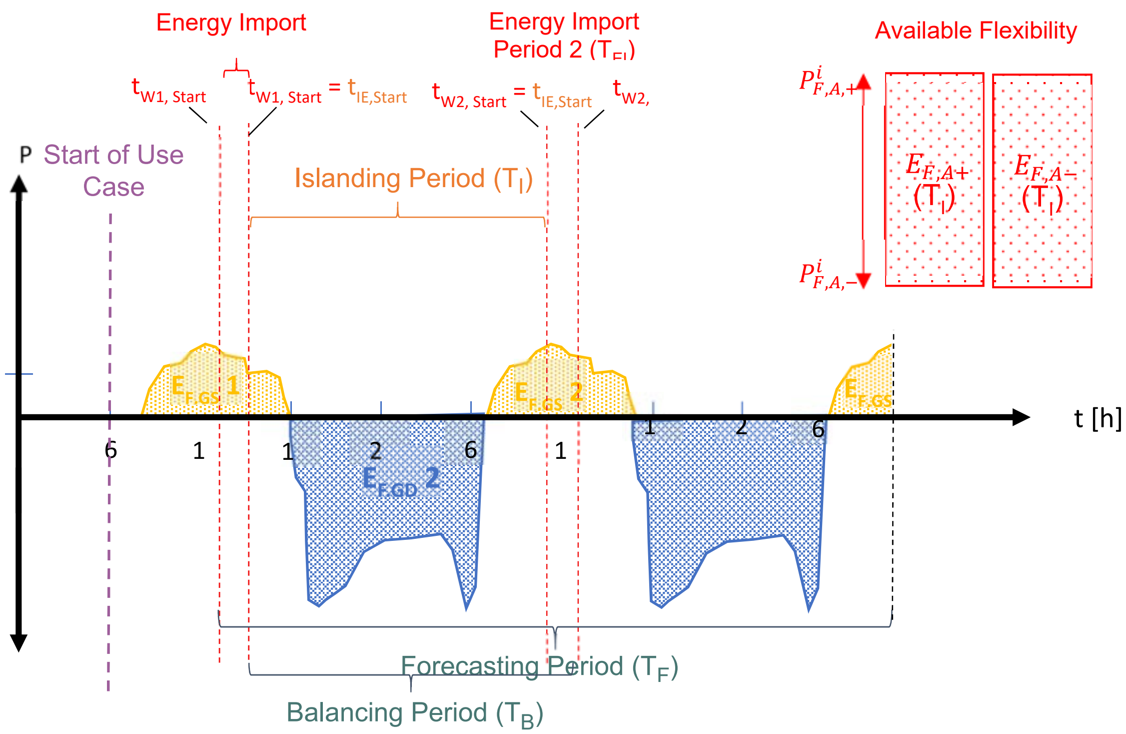

Figure 12: Use Case 3 Algorithm Logic - Forecast of load exchange at grid connection point (PF; TEI)

3.) Determination of Available Flex and Status of the grid

Before the use case starts, the Dispatcher module (Flex Detector) determines available flexibility ($E^{i}_{F,A,+}$, $E^{i}_{F,A,+}$ $P^{i}_{F,A,+}$ a $P^{i}_{F,A,-}$) with the approach describes in section 5.1. – 3. In order to compute the aggregated flexibilities, the Flex Detector applies the algorithm displayed in section 6.5.1. Algorithm input data will be collected from the relevant asset $i \in \mathcal{N}$, where $\mathcal{N}$ is the set of all available flexibilities, and base data from base master storage ($SOC^{i}_{F;MIN}$, $SOC^{i}_{F,MAX}$) and real time measured data from assets in the field ($SOC^{i}_{F,Real}$, P^{i}_{Real}). Further, the real-time load exchange at the grid connection point P_{TEI} will be determined.

4.) Balancing – Determination of P_{TFD} (t)

The Balancer module determines the optimal strategy of aggregated activation of available flexibility $P_F\,(t)$ in order to minimise the load exchange $P_{F;\,TEI}$ within the period T_I and necessary energy and value power that has to be imported during the time window from $t_{W1,\,Start}$ to $t_{W1,\,Start}$ set by the CGC. Within the period T_i the same logic of islanding balancing as describes in section 5.1- 4.2 will be applied. In case available flexible power $P^i_{F,A,+}$, $P^i_{F,A,-}$ or energy $E_{F,A+}$, $E_{F,A-}$ are not sufficient for compensation of the forecasted imbalances, an optimization described in section 5.1 4.II will be applied in order to minimise the load exchange. The applied algorithm is displayed in section 6.4.4.

Figure 12 shows an example of the forecasted load exchange and amount of energy generated in the period T_i indicated in yellow ($E_{F,GS}\,1$ and $E_{F,GS}\,2$) as well as amount of energy deficits ($E_{F,\,GD}\,2$). Figure 13 visualises the optimization problem to be solved by the UC 3 balancing algorithm. The available amount storage capacity $E_{F,A+}(T_I)$ will not be sufficient to compensate $E_{F,\,GD}\,2$ within the period T_I. The balancing algorithm will determine the appropriate amount of energy E_i for the period T_{EI} in order to compensate $B1+$, $B1-$ and $B2+$. At the point of time $t_{W1,\,End}$ available storages will not be fully charged, otherwise $B1+$ could not be compensated. At the point of time $t_{Deficit,\,Start}$ to be determined by the algorithm, the available storages have to be fully charged in order to maximise compensation of energy deficits, indicated a blue area. In result the forecasted amount of generation surplus $B1$- will be compensated. At the point of time $t_{Deficit,\,End}$ storages should be fully discharged. The point of time $t_{W2,\,Start}$ is the end of the balancing period (T_B) and islanding period (T_i).

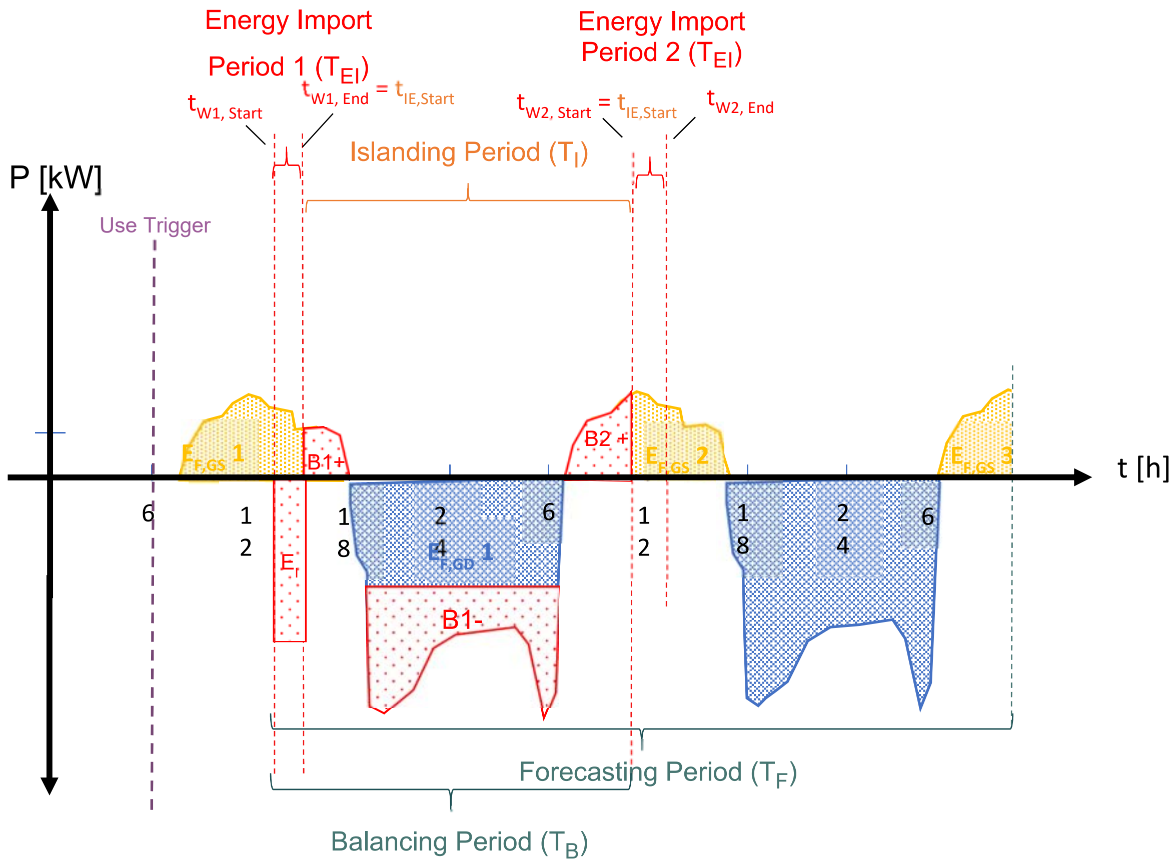

Figure 13: Use Case 3 Algorithm Logic - Optimization of load flow at grid connection Point (PTFD (t)

Rules/Restrictions:

- Available storage capacity $E_{F,A+}$ and $E_{F,A-}$ power $P^i_{F,A,+}$, $P^i_{F,A,+}$ at $t_{W1,\,Start}$ is a given value determined by the Dispatcher module.
- At the point of time $t_{W1,\,End}$ the flexible storages should be almost but not fully charged, in order compensate $B1+$.
- $B1$- shall be maximised.

- At the point of time $t_{Deficit,\ End}$ the storages have to be fully discharged.
- Within the balancing period T_B the sum of imported and stored energy (E_F) and curtailed generated energy ($B1+$) have to equal the available energy storage capacity $E_{F,A+}$ (T_I) in order to make maximum use locally generated energy; $(E_F) + (B1+) = E_{F,A+}$.
- The value of power P_I within period T_{TEI} has to be minimised and smaller than $P^{i}_{F,A,-}$.

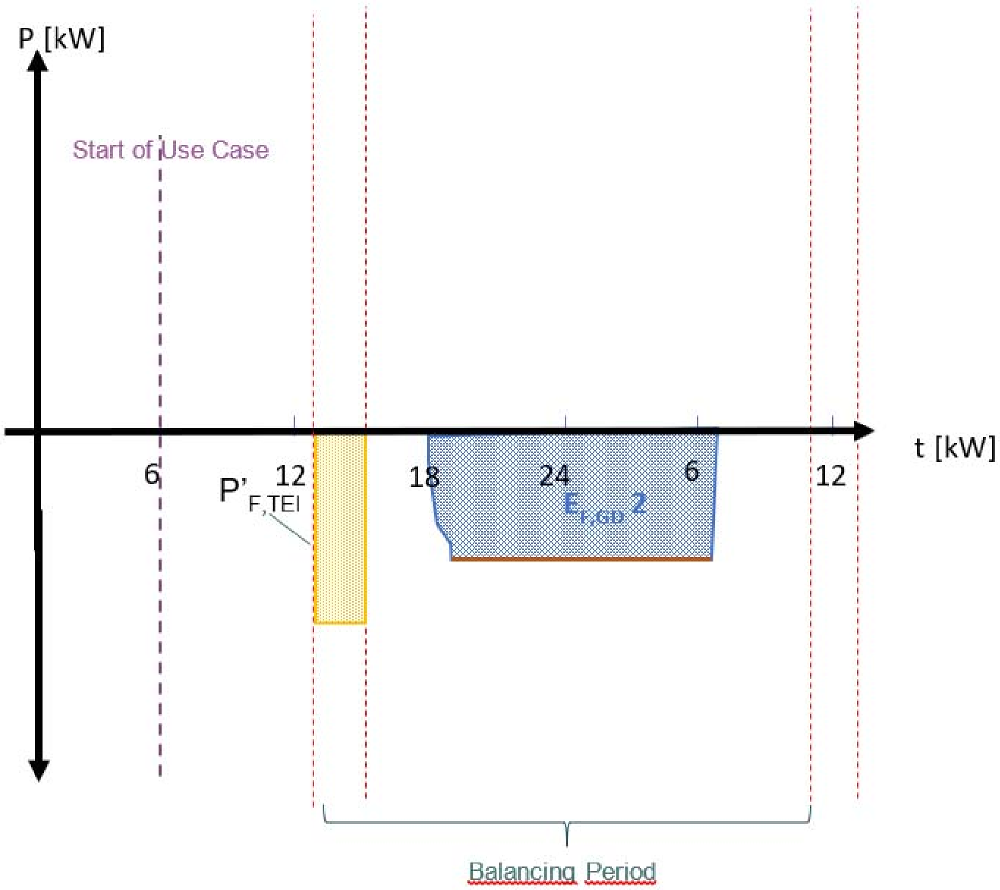

Figure 14: Use Case 3 Algorithm Logic – Forecasted resulting load flow at grid connection point after UC application

Determination/ Output:

Aggregated value of power feed or withdraw from the grid:

- $P_F\ (t)$ for the period from $t_{W1,\ Start}$ to $t_{W1,\ End}$
- $P_F\ (t)$ for the period from $t_{W1,\ End}$ to $t_{W2,\ Start}$
- $P_F\ (t)$ for the period from $t_{W2,\ Start}$ to $t_{W2,\ End}$

5.) Dispatching and Execution - Result Energy Flow (P'F, TEI):

The result of the optimization of the Balancer module is an aggregated setpoint schedule $P_F\ (t)$ covering the balancing period (T_B) which has to be disaggregated into individual setpoint for local flexibilities by the Dispatcher module as described in section 5.1 5. As a result of flex activation, the forecasted load curve $P_{F,TEI}$ (Figure 12) will be shifted. The forecasted result is outlined in Figure 14 and shows the load exchange at the grid connection ($P'_{F,\ TEI}$).

5.4 Use Case 4 – Bulk Energy Export

The principle of UC 4 is the same as that of UC 3. With the help of the ALF-C, the aim is to enable the LV grid or LEC to move from the paradigm of real-time supply to time-delayed supply by integrating local flexibilities. Whereas UC 3 focuses on load-driven network, requiring a bulk provision of energy in advance, UC 4 focuses on generation-driven network, requiring a delayed export of buffered energy surplus at suitable times set by the CGC.

The principle of delayed export of generation surplus is based on the concept that the CGC defines time slots for the energy export (T_{EE}) at the grid connection point, without restrictions regarding P_{TEI} or E_{TEI}. Within a time slot, the ALF-C will export enough power/energy (discharge of storages), respecting the limits of available flexibility, so that enough storage capacity is available within the period between the time slots (Islanding period - $\mathrm{T_I}$) to run the grid in island mode. If there is not enough flexibility available, the optimal point in time for the activation of the storage flexibilities will be determined with the help of an optimization in order to minimise the load peaks within the islanding period.

1.) Operator Input/Grid Control Setting

The use case Algorithm starts with an operator input setting Use Case 4 and relevant variables via a GUI at the point of time $t_{UC;\ trigger}$. Here, the GCC sets time slots for the export of energy surplus along the LV/MV grid connection point for at least 48h ahead. For each day, one time slot will be specified. Figure 15 visualises an example at which for day 1 a time window is set with the starting point ($t_{W,\ Start}$) at 13:00 and end time ($t_{W,\ End}$) at 15:00 and for day 2 $t_{W,\ Start}$ = 11:00 and $t_{W,\ Start}$ = 13:00.

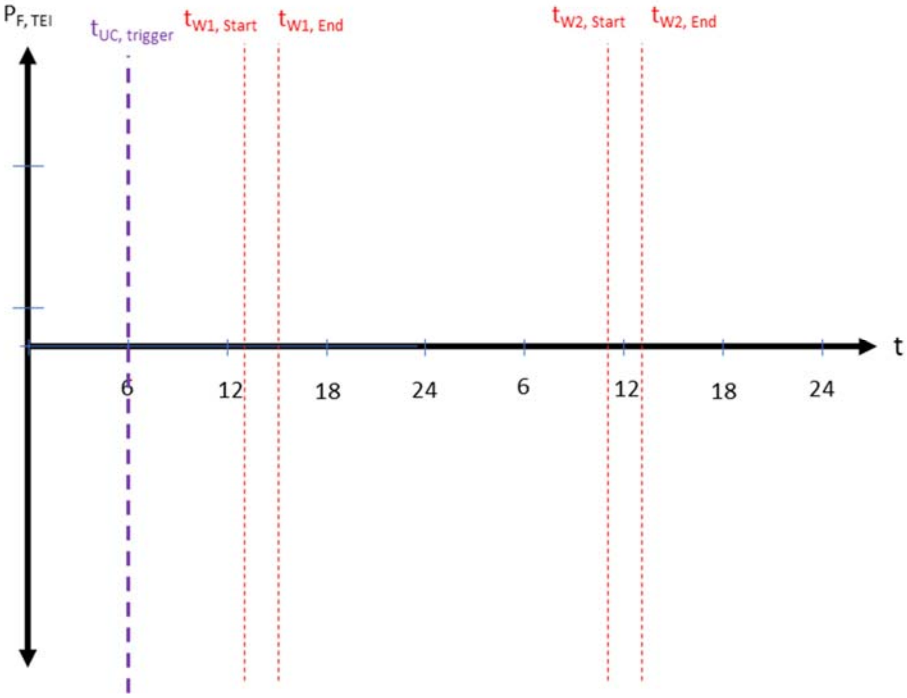

Figure 15: Use Case 4 Algorithm Logic- Example of Time Slot for Energy Export

2.) Forecast & Determination of Available Flex

The total generation and demand and the resulting load exchange at the LV/MV grid connection point will be forecasted up to 48 hours ahead ($P_{F;\ TEI}(t{+}48h)$) based on a forecast of total generation $P_{F;\ TG}(t{+}48h)$ and total consumption $P_{F;\ TC}(t{+}48h)$. The forecast will be determined for the forecasting period (T_F). Different types of forecast will be applied depending on the stage of implementation. Different forecast types are described in section 4.5. The algorithms for each forecast type are detailed in section 6.3. Figure 16 displays on an example of a generation driven scenario the forecast of power exchange at the grid connection point $P_{F;\ TEI}$ for a period of 48 hours. The line displays value of forecasted load

($P_{F,TEI}$) and the area between the line the amount of energy. Export from LV grid into MV grid are indicated in yellow and imports are indicated in blue.

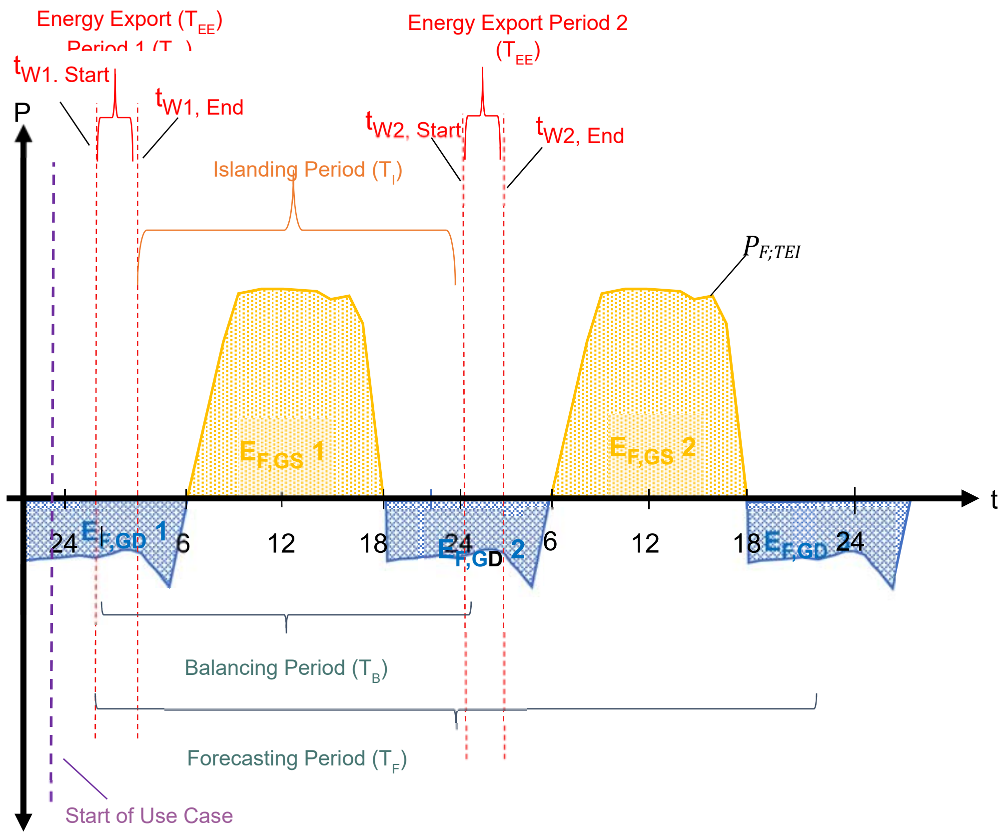

Figure 16: Use Case 4 Algorithm Logic - Forecast of Load Exchange at Grid Connection Point (PF; TEI)

3.) Determination of Balancing Load P_{TFD} (t)

The Balancer module determines the optimal strategy for aggregated activation of available flexibility P_F (t) in order to minimise the load exchange $P_{F;\,TEI}$ within the period T_I and required energy and the value of power that has to be imported during the time window from $t_{W1,\,Start}$ to $t_{W2,\,End}$ set by the CGC. Within the period T_i the same logic of islanding balancing as described in section 5.1.4 – 2 will be applied. In case available P_F and E_F are not sufficient for compensation of the imbalances, an optimization will be applied in order to minimise the load exchange.

The differences towards UC 3 is visualised in Figure 17. The Balancer has to determine the required amount of energy (E_I) and power ($P_{UC4,\,Peak}$) to be exported within the period ($T_{EE,\,1}$) from the LV grid into the MV grid, in order to have enough storage capacity and flexibility available for an energetical islanding within the period T_I. The applied algorithm is detailed in section 6.4.5.

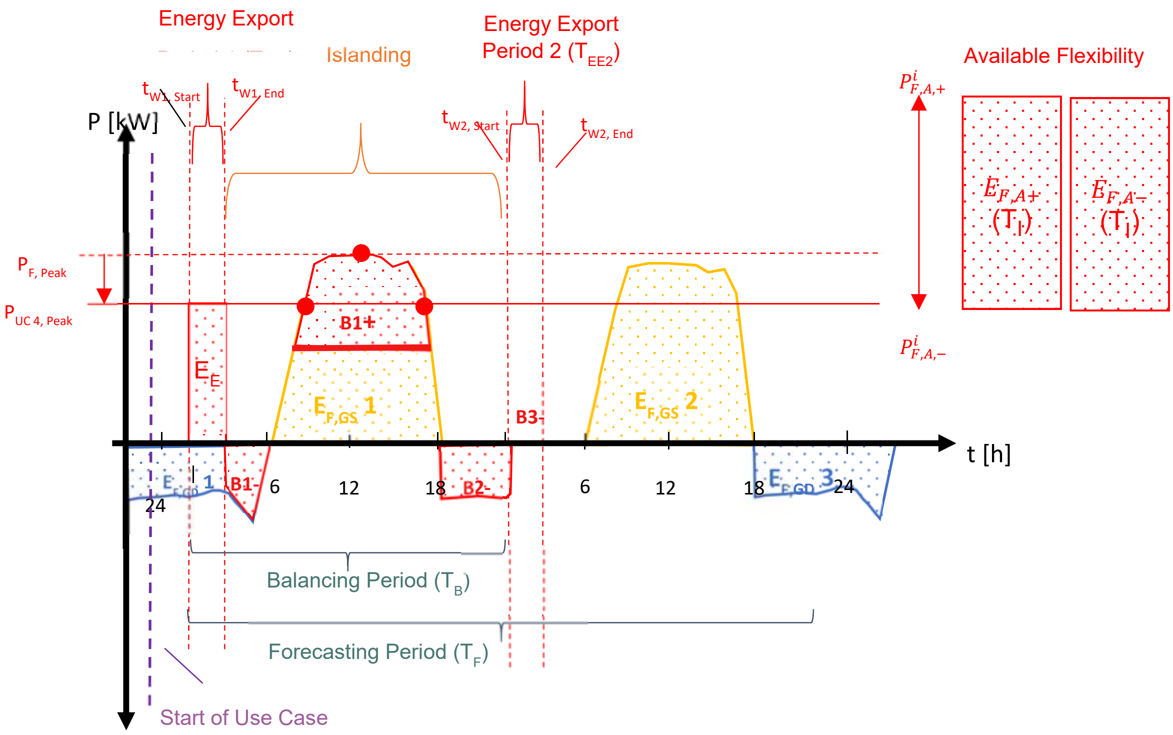

Figure 17: Use Case 4 Algorithm Logic – Optimization of Load Flow at Grid Connection Point (PTFD (t)

Rules/Restrictions:

- Available storage capacity $E_{F,A+}$ and $E_{F,A-}$ power $P^i_{F,A,+}$, $P^i_{F,A,+}$ at $t_{W1,\,Start}$ define the limits of available flexibility determined by Dispatcher module.
- At the point of time $t_{Surplus,\,Start}$ local storages have to be fully discharged until the minimum value
- With the balancing period $(TB)\ EE\ =\ B1 -\ B1-;\ EE\ <=\ E_{F,A+}$
- At the point of time $t_{W1,\,End}$ the flexible storages should be almost but not fully discharged, in order to compensate $B1\ +$.
- $B1\ +$ shall be maximised
- At the point of time $t_{Surplus,\,Start}$ the storages have to be fully discharged.

  The value of power P_I within period TEI has to be minimised and smaller than $P^i_{F,A,+}$.

Determination/Output:

Aggregated setpoint schedule (value of power over time) to be provided by flexible assets (to be feed or withdrawn from the grid:

- $P_F\ (t)$ for the period from $t_{W1,\,Start}$ to $t_{W1,\,End}$
- $P_F\ (t)$ for the period from $t_{W1,\,End}$ to $t_{W2,\,Start}$
- $P_F\ (t)$ for the period from $t_{W2,\,Start}$ to $t_{W2,\,End}$

4.) Execution (Dispatching)

The schedule of $P_F(t)$ determined by the Balancer module will be disaggregated into individual setpoints for local available flexible assets and dispatched by the Dispatcher module. The result of the optimization is given in Figure 18. It shows that the peak value of the absolute amount of $P_{F,\ Peak}$ will be decreased to $P_{UC\ 4\ Peak}$. The resulting power flow at the LV/MV grid connection point is given in Figure 8. The applied algorithm is given in section 6.5.2.

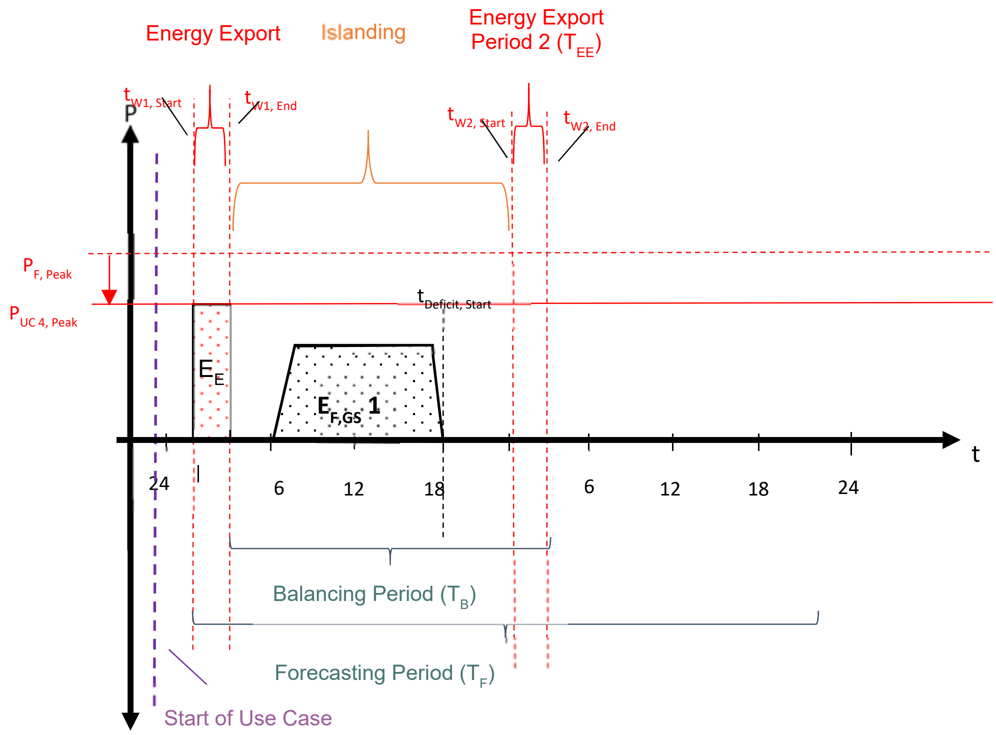

Figure 18: Use Case 4 Algorithm Logic – Forecasted Resulting Load Flow at Grid Connection Point after Use Case Application

6 Algorithms

6.1 Notations and Parameters for Algorithms

Notations

$ch \rightarrow$ *charge;*

$dis \rightarrow$ *discharge*

$flex \rightarrow$ *aggregated flexibility*

$F \rightarrow$ *Forecast*

$flex_i \rightarrow$ *ith flexibility asset*

$TG \rightarrow total\ generation$

$TC \rightarrow total\ consumption$

$TEI \rightarrow total\ export/import$

$TCB \rightarrow total\ charge/discharge$

$exp \rightarrow export$

$imp \rightarrow import$

$req \rightarrow required$

$uc \rightarrow use\ case$

$t \rightarrow time$

Parameters

N – Number of batteries in the field

P_{F+}^{i} , $P_{fi,ch}$ – Respective available power for increase of consumption or decrease of feed

P_{F-}^{i} , $P_{fi,dis}$ – Respective available power for decrease of consumption or increase of feed

E_{F-}^{i} / $E_{fi,ch}$ – Respective available storage capacity for charge

E_{F+}^{i} / $E_{fi,dis}$- Respective available capacity for discharge

$SOC_{F;MIN}^{i}$ – Minimum state of charge of storage of flexibilities

$SOC_{F;MAX}^{i}$ - Maximum state of charge of storage of flexibilities

$SOC_{F;Measured}^{i}$ – Measured real time state of charge

E_{N}^{i} – Nominal storage capacity

P_{N}^{i} – Nominal active power

P_{TEI} ; $P_{TEI,meas}$- Measured real time power consumption/feed

P_F ; P_{TCB}^{m} – Nominal aggregated setpoint of power for increase or decrease of load

$P_{F,A,+}$; $P_{f,dis}$- Aggregated active power for increase load/decrease feed

$P_{F,A,-}$; $P_{f,ch}$- Aggregated active power for decrease load/increase feed

$E_{F,A,+}$; $E_{f,ch}$ Aggregated amount of energy available for discharging

$P_{F,A,-}$; $E_{f,dis}$- Aggregated capacity available for charging

P_F – Aggregated value of power for flex activation determines by Balancing Module

$P^i_{F;S}$ – Setpoint active power value for asset i

6.2 Actors interactions

The following figure shows the parameter exchange between the modules of the ALF-C.

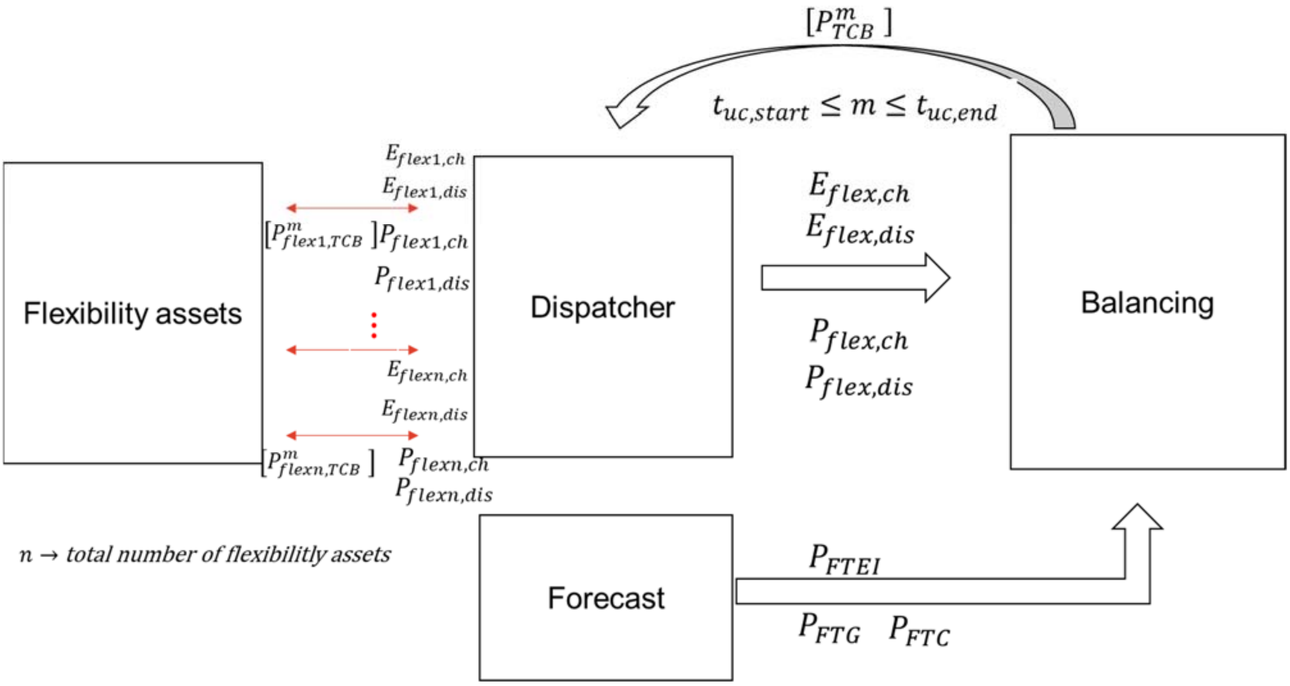

Figure 19: Algorithm Module and Actor Interaction

6.3 Forecasting Algorithm

In the following the algorithms used for the different forecasting quality levels are described.

6.3.1 Forecasting – Type 1

Output: $P_{F;\,TEI}$ (t+24h)

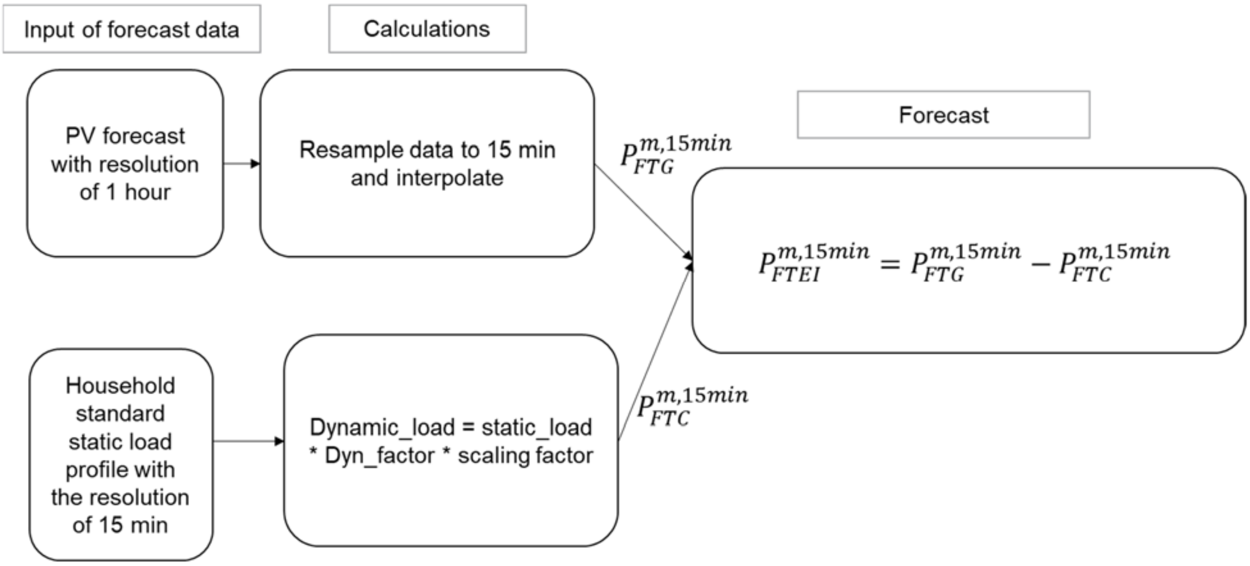

Figure 20: Algorithm Forecast Type 1

6.3.2 Forecasting – Type 2

Output: $P_{F;TEI}$ (t+24h)

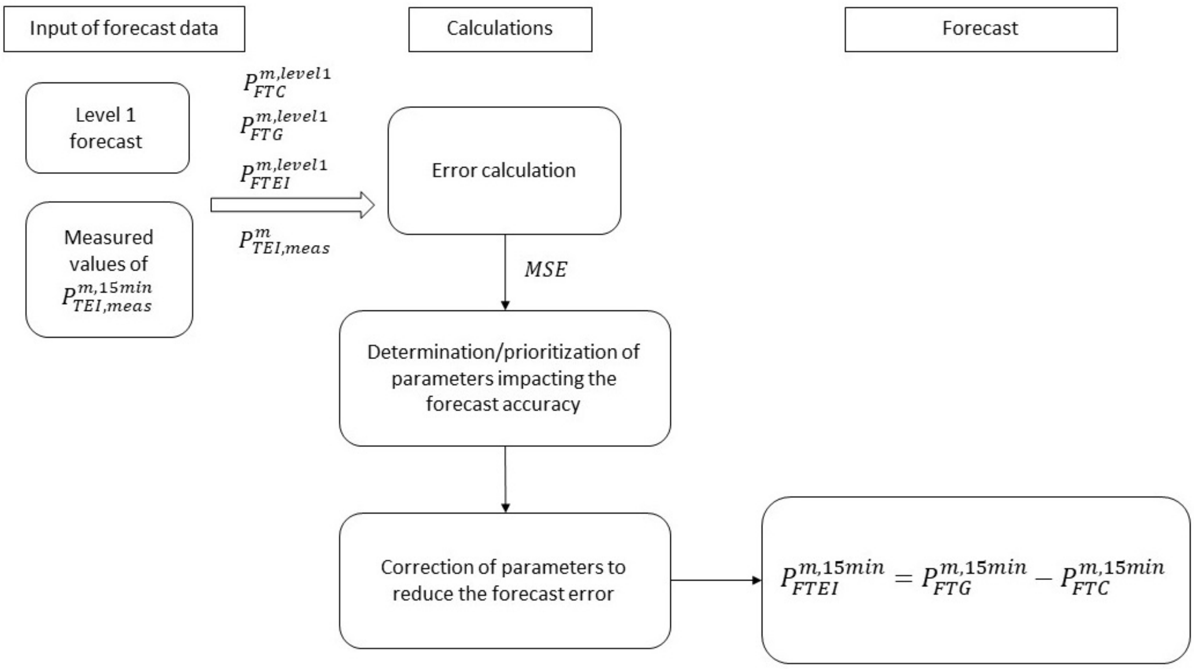

Figure 21: Algorithm Forecast Type 2

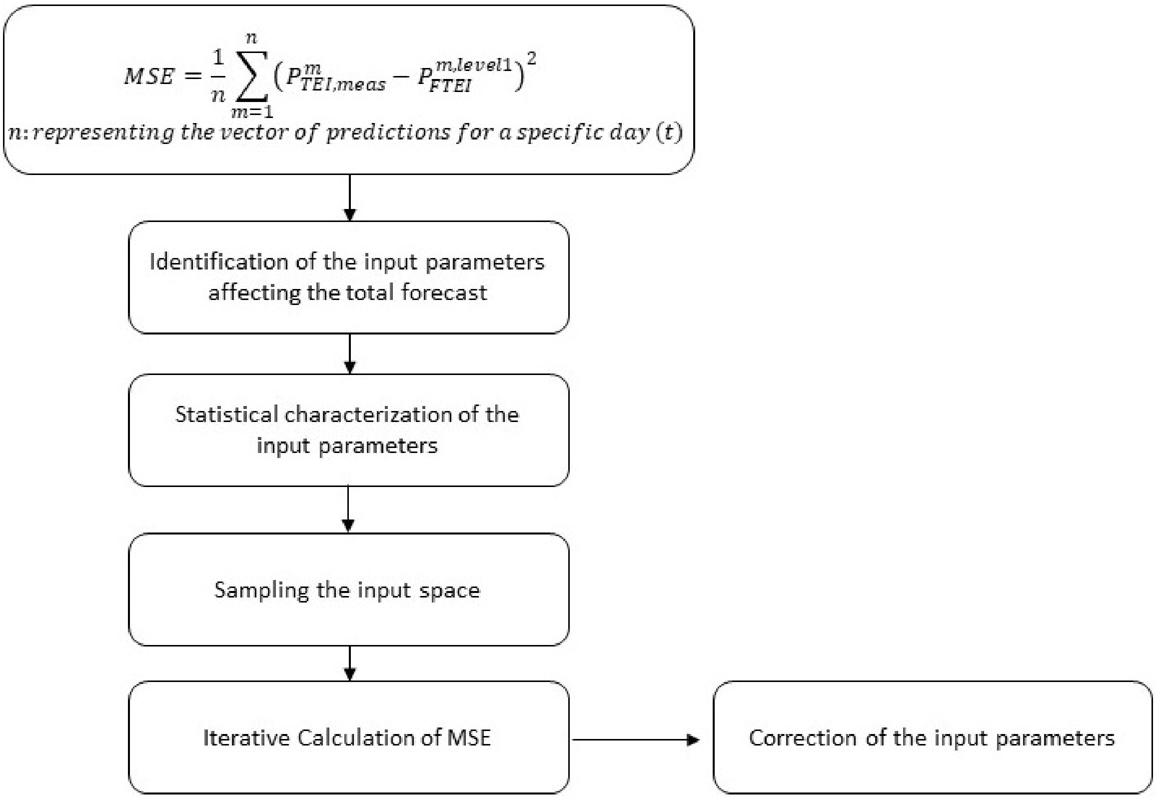

Figure 22: Algorithm Forecast Type 2 - Correction Mechanism

6.3.3 Forecasting – Type 3

Output: $P_{F;TEI}$ (t+24h)

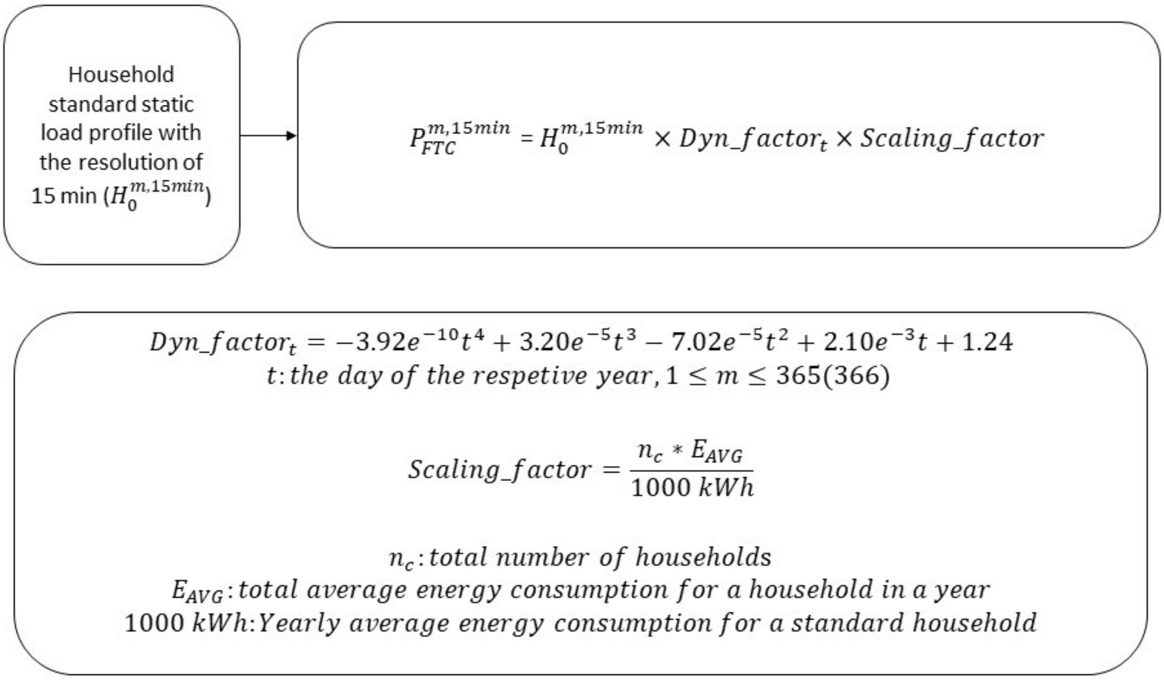

Figure 23: Algorithm Forecast Type 3

6.4 Balancing Algorithms

In the following the algorithms used by the Balancer module to perform the field-test use cases are described.

6.4.1 Algorithm 1 Balancing UC 1 - Step 0

During the measurement and steering process in which the target value P'_{TEI}=0 the Balancer calculates the setpoints with the following algorithm.

Input: $P_{F;TEI}(t+24h)$, $P'_{TEI}(P_{TEI,req})$, $t_{IE,Start}$, $t_{IE,End,}$, $E_{f,ch}$, $E_{f,dis}$, $P_{f,ch}$ $P_{f,dis}$

Output: P_{TCB}

Internal determined Values: $t_{Surplus,\ Start;}$ $t_{Surplus,\ End,}$ $t_{Deficit,\ Start,}$ $t_{Deficit,\ End}$

Algorithm:

1: $if\ P^m_{TEI,meas} < 0 \rightarrow\ activation\ of\ discharge\ mechanism \rightarrow \left|P^m_{TEI,meas}\right| = P^{m+1}_{dis}$

2: $if\ P^m_{TEI,meas} > 0 \rightarrow activation\ of\ charge\ mechanism\ \rightarrow\ P^m_{TEI,meas} = |P^{m+1}_{ch}|$

$$In\ other\ words\colon\ P^m_{TEI,meas} = -P^{m+1}_{TCB}$$

$$Constraints\colon \begin{cases} |P^{m+1}_{ch}| \leq\ P^m_{f,ch}\ \ |E^{m+1}_{ch}| \leq E^m_{f,ch} \\ \ P^{m+1}_{dis} \leq\ P^m_{f,dis}\ \ E^{m+1}_{dis} \leq E^m_{f.dis} \end{cases}$$

$$P^m_{TCB} = -P^m_{TEI,meas} \qquad\qquad t_{uc,start} \leq m \leq t_{uc,end}$$

$$E^m_{TCB} = P^{m+1}_{TCB}\Delta T$$

$$\boldsymbol{if} \begin{Bmatrix} P^m_{TCB} \geq 0 \rightarrow if \begin{Bmatrix} |P^m_{TCB}| \leq\ P^m_{f,dis} \rightarrow continue \\ else P^m_{TCB} = P^m_{f.dis} \rightarrow E^m_{TCB} = P^m_{TCB}\Delta T \end{Bmatrix} \rightarrow if \begin{Bmatrix} |E^m_{TCB}| \leq\ E^m_{f,dis} \rightarrow continue \\ else P^m_{TCB} = 0 \rightarrow continue \end{Bmatrix} \\ P^m_{TCB} < 0 \begin{Bmatrix} |P^m_{TCB}| \leq\ P^m_{f,ch} \rightarrow continue \\ else P^m_{TCB} = -P^m_{f.ch} \rightarrow E^m_{TCB} = P^m_{TCB}\Delta T \end{Bmatrix} \rightarrow if \begin{Bmatrix} |E^m_{TCB}| \leq\ E^m_{f,ch} \rightarrow continue \\ else P^m_{TCB} = 0 \rightarrow continue \end{Bmatrix} \end{Bmatrix}$$

$$\rightarrow report\ P^m_{TCB} \rightarrow continue$$

6.4.2 Algorithm 2 Balancing UC 1 – Step 1

For the schedule-based balancing, the algorithm used by the Balancer module looks like the following. In contrast to Step 0 forecasting is included.

Balancing Algorithm Input:

$t_{iw,start}, t_{iw,end}, E_{flex,ch}, E_{flex,dis}, P_{flex,ch}, P_{flex,dis}, P_{FTEI}, P_{FTG}, P_{FTC}$

Balancing Algorithm Output: P^m_{TCB} $(\ t_{uc,start} \leq m \leq t_{uc,end})$

Algorithm Flow Chart:

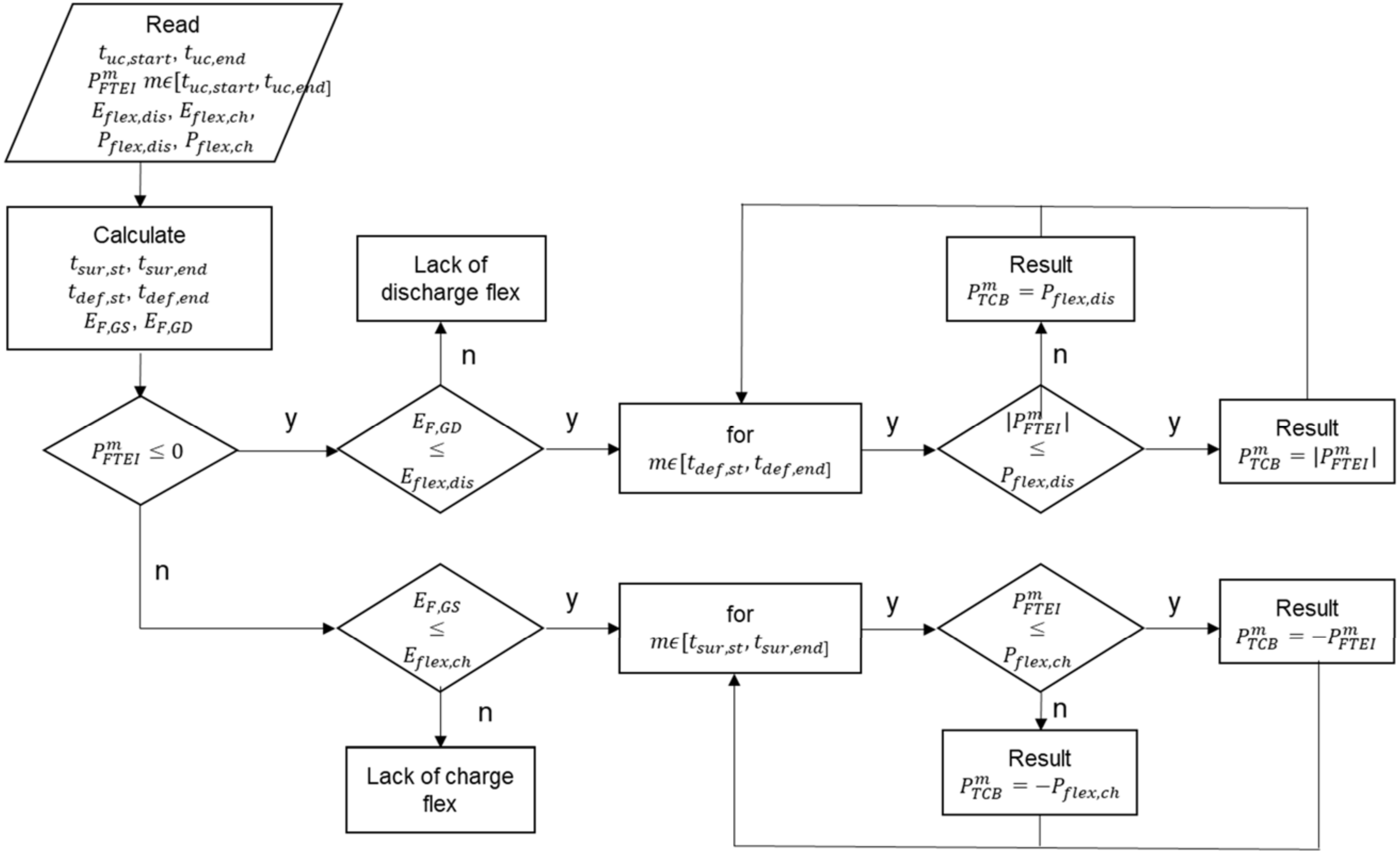

Figure 24: Use Case 1 Step 1 - Balancing Algorithm Flow Chart

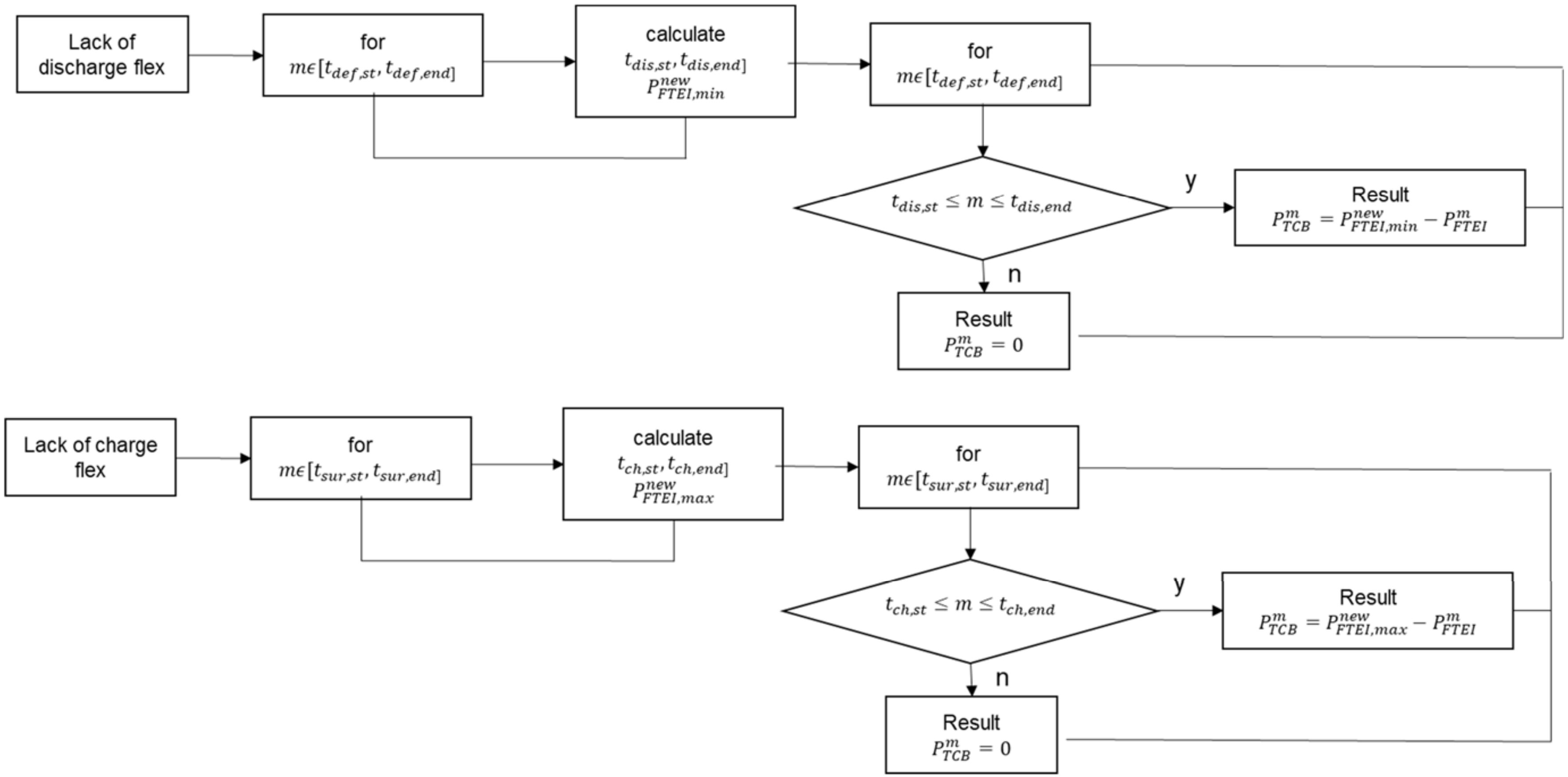

Figure 25: Use Case 1 Step 1 - Balancing Algorithm Flow Chart

Algorithm:

1: $if\ P^{m}_{TEI,req} - P^{m}_{TEI,meas} > 0 \rightarrow$ *activation of discharge mechanism* $\rightarrow P^{m}_{TEI,req} - P^{m}_{TEI,meas} = P^{m+1}_{dis}$

2: $if\ P^{m}_{TEI,req} - P^{m}_{TEI,meas} < 0 \rightarrow$ *activation of charge mechanism* $\rightarrow P^{m}_{TEI,req} - P^{m}_{TEI,meas} = P^{m+1}_{ch}$

3: $P^{m+1}_{TCB} = P^{m}_{TEI.req} - P^{m}_{TEI,meas}$

4: $E^{m+1}_{TCB} = P^{m+1}_{TCB}\Delta T$

5:

$$\begin{cases} if\, P^{m+1}_{TCB} \geq 0 \rightarrow if\, |P^{m+1}_{TCB}| \leq\ P^{m}_{f,dis}\ |E^{m+1}_{TCB}| \leq E^{m}_{f.dis} \rightarrow report\ P^{m+1}_{TCB}; else\ P^{m+1}_{TCB} = 0 \rightarrow continue; \\ \quad \textit{else}\{if\, |P^{m+1}_{TCB}| \leq\ P^{m}_{f,ch}\ \&|E^{m+1}_{TCB}| \leq E^{m}_{f,ch} \rightarrow report\ P^{m+1}_{TCB}; else\ P^{m+1}_{TCB} = 0 \rightarrow continue; \end{cases}$$

6.4.3 Algorithm 3 – Balancing Use Case 2

During the Use Case 2 the Balancer module needs to calculate setpoints in order to achieve the previous set P'TEI. Here a measurement and steering process is used. The algorithm is described in the following.

Balancing Module Input:

Balancing Module Output: P_{TFD}

Algorithm:

1: $if\ P_{TEI,req}^{m} - P_{TEI,meas}^{m} > 0 \rightarrow$ *activation of discharge mechanism* $\rightarrow P_{TEI,req}^{m} - P_{TEI,meas}^{m} = P_{dis}^{m}$

2: $if\ P_{TEI,req}^{m} - P_{TEI,meas}^{m} < 0 \rightarrow$ *activation of charge mechanism* $\rightarrow P_{TEI,req}^{m} - P_{TEI,meas}^{m} = P_{ch}^{m}$

3: $P_{TCB}^{m} = P_{TEI.req}^{m} - P_{TEI,meas}^{m} \qquad t_{uc,start} \leq m \leq t_{uc,end}$

4: $E_{TCB}^{m} = P_{TCB}^{m} \Delta T$

$$if \begin{Bmatrix} P_{TCB}^{m} \geq 0 \rightarrow if \begin{Bmatrix} |P_{TCB}^{m}| \leq P_{f,dis}^{m} \rightarrow \text{continue} \\ else P_{TCB}^{m} = P_{f.dis}^{m} \rightarrow E_{TCB}^{m} = P_{TCB}^{m} \Delta T \end{Bmatrix} \rightarrow if \begin{Bmatrix} |E_{TCB}^{m}| \leq E_{f,dis}^{m} \rightarrow continue \\ else P_{TCB}^{m} = 0 \rightarrow continue \end{Bmatrix} \\ P_{TCB}^{m} < 0 \begin{Bmatrix} |P_{TCB}^{m}| \leq P_{f,ch}^{m} \rightarrow \text{continue} \\ else P_{TCB}^{m} = -P_{f.ch}^{m} \rightarrow E_{TCB}^{m} = P_{TCB}^{m} \Delta T \end{Bmatrix} \rightarrow if \begin{Bmatrix} |E_{TCB}^{m}| \leq E_{f,ch}^{m} \rightarrow continue \\ else P_{TCB}^{m} = 0 \rightarrow continue \end{Bmatrix} \end{Bmatrix} \rightarrow$$

$report\ P_{TCB}^{m}$

6.4.4 Algorithm 3 – Balancing Use Case 3

In Use Case 3 the following algorithm is used by the Balancer module to achieve energy import in bulk. Forecasting is used not only for a prediction of the demand but also for the amount of energy that will be imported during the given time slot.

Balancing Algorithm Input:

$t_{iw,start}, t_{iw,end}, E_{flex,ch}, E_{flex,dis}, P_{flex,ch}, P_{flex,dis}, P_{FTEI}, P_{FTG}, P_{FTC}$

Balancing Algorithm Output: $P_{TCB}^{m}\ (\ t_{uc,start} \leq m \leq t_{uc,end})$

Algorithm:

$$if\ P_{FTEI}^{m} < 0 \rightarrow\ activation\ of\ discharge\ mechanism \rightarrow |P_{FTEI}^{m}| = P_{dis}^{m}$$

$$if\ P_{FTEI}^{m} > 0 \rightarrow activation\ of\ charge\ mechanism\ \rightarrow P_{FTEI}^{m} = |P_{ch}^{m}|$$

$$Constraints: \begin{Bmatrix} |P_{ch}^{m}| \leq P_{flex,ch}\ |E_{ch}^{m}| \leq E_{flex,ch} \\ P_{dis}^{m} \leq P_{flex,dis}\ E_{dis}^{m} \leq E_{flex,dis} \end{Bmatrix}\ \&\ E_{import} \leq E_{flex,ch}$$

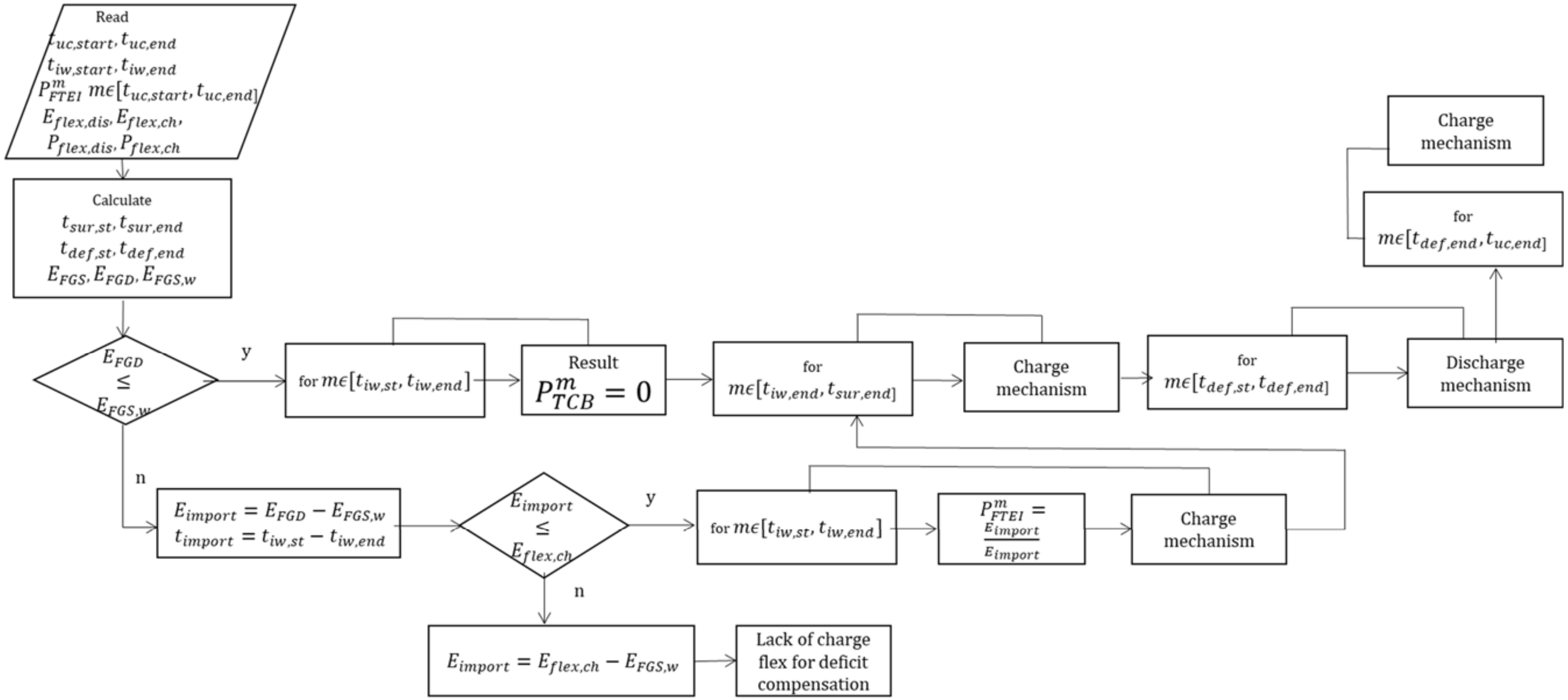

Figure 26: Use Case 3 - Balancing Algorithm Flow Chart 1

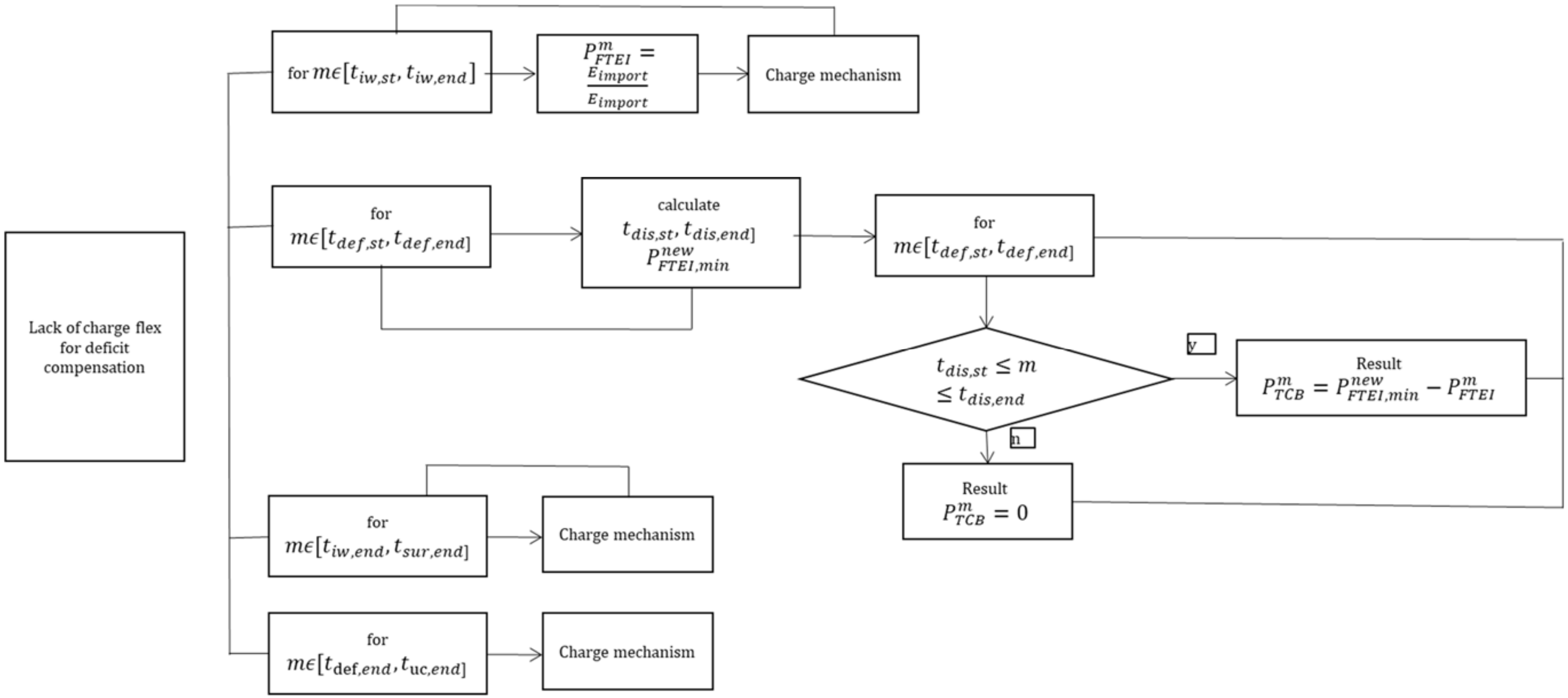

Figure 27: Use Case 3 - Balancing Algorithm Flow Chart 2

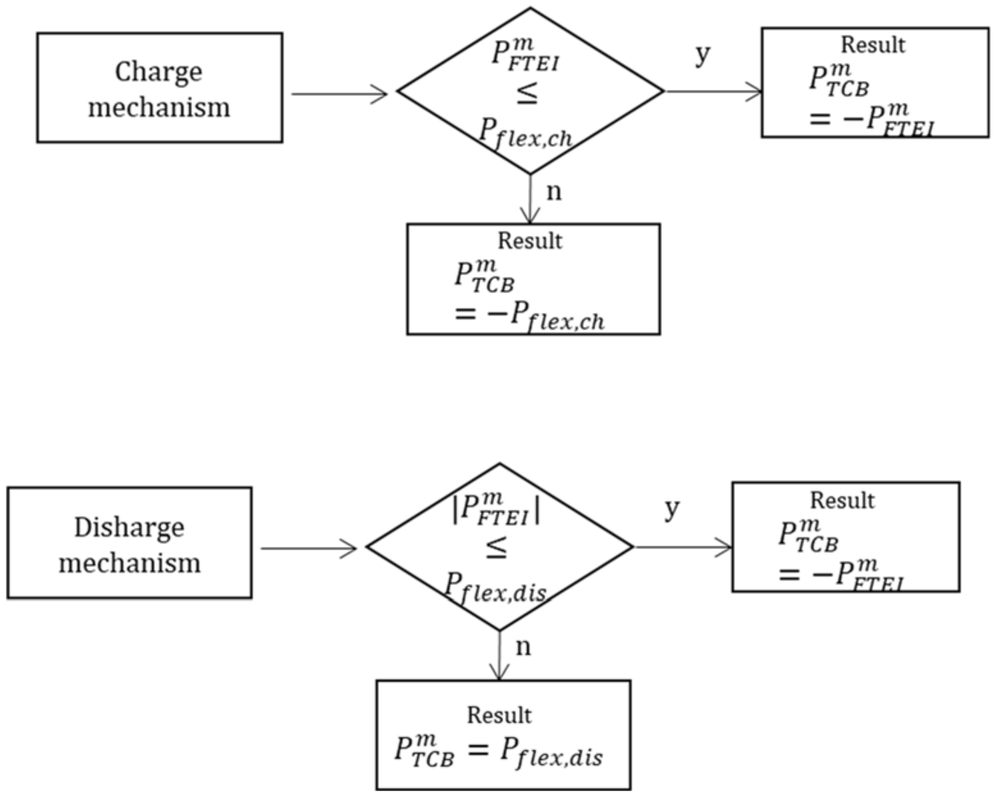

Figure 28: Use Case 3 - Balancing Algorithm Flow Chart 3

6.4.5 Algorithm 4 – Balancing Use Case 4

In Use Case 4 the following algorithm is used by the Balancer module to achieve energy export in bulk. Forecasting is used to calculate the amount of energy that needs to be exported during the given time slot.

Balancing Algorithm Input: $t_{iw,start}, t_{iw,end}, E_{flex,ch}, E_{flex,dis}, P_{flex,ch}, P_{flex,dis}, P_{FTEI},$

Balancing Algorithm Output: P_{TCB}^{m} $(\ t_{uc,start} \leq m \leq t_{uc,end})$

Algorithm:

$$if\ P_{FTEI}^{m} < 0 \rightarrow\ activation\ of\ discharge\ mechanism \rightarrow |P_{FTEI}^{m}| = P_{dis}^{m}$$

$$if\ P_{FTEI}^{m} > 0 \rightarrow activation\ of charge\ mechanism\ \rightarrow P_{FTEI}^{m} = |P_{ch}^{m}|$$

$$Constraints: \begin{cases} |P_{ch}^{m}| \leq P_{flex,ch}\ |E_{ch}^{m}| \leq E_{flex,ch} \\ P_{dis}^{m} \leq P_{flex,dis}\ E_{dis}^{m} \leq E_{flex,dis} \end{cases} \&\ E_{import} \leq E_{flex,ch}$$

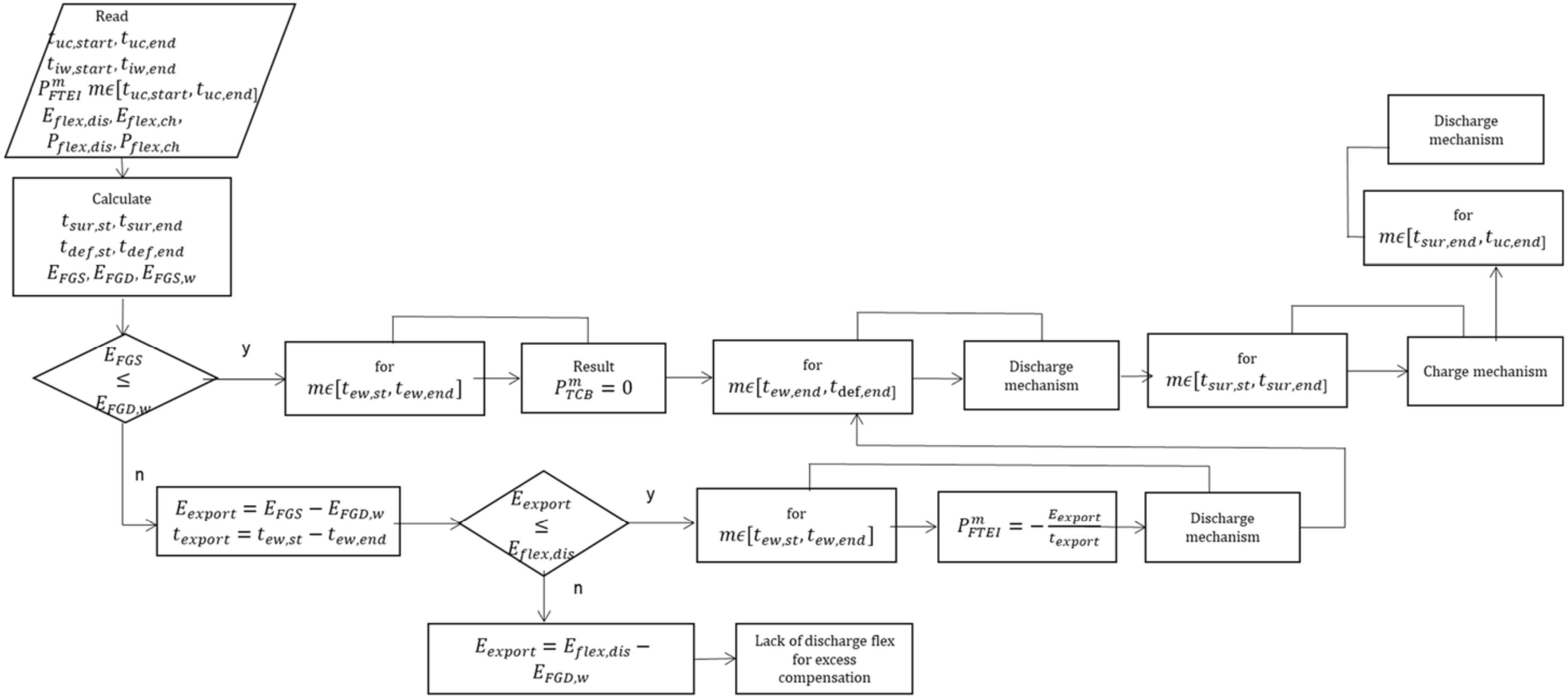

Figure 29: Use Case 4 – Balancing Algorithm Flow Chart 1

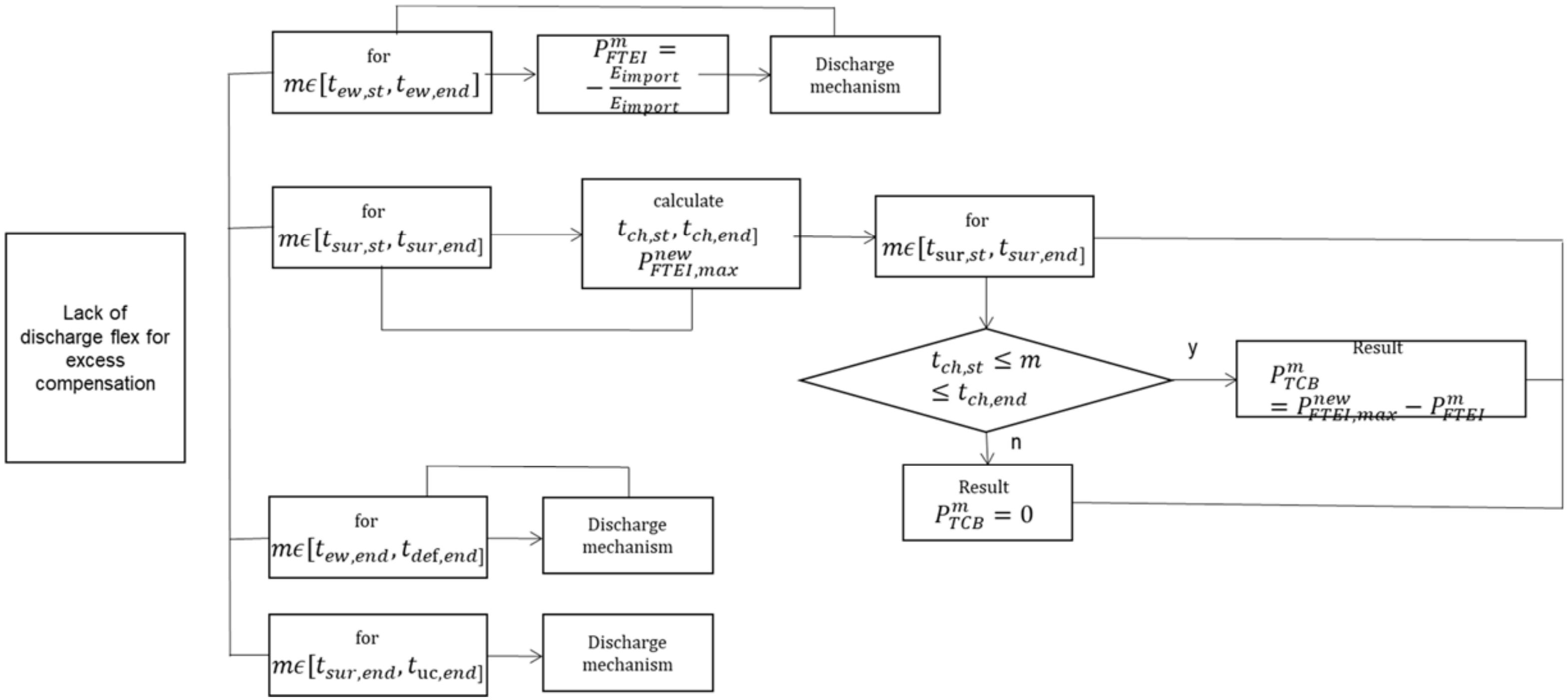

Figure 30: Use Case 4 - Balancing Algorithm Flow Chart 2

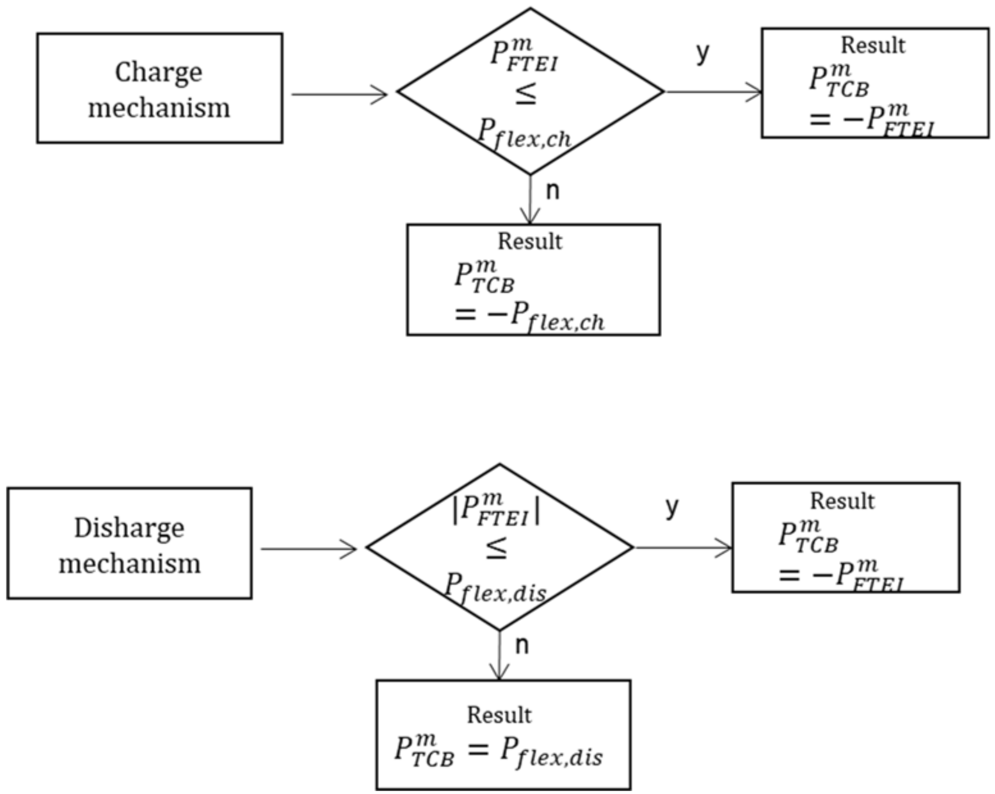

Figure 31: Use Case 4 - Balancing Algorithm Flow Chart 3

6.5 Dispatcher

6.5.1 Algorithm Flex Detector – Flex Aggregation

Input: $SOC^i_{F;MIN}$, $SOC^i_{F;MAX}$, $SOC^i_{F;Real}$, E^i_N, P^i_N, P^i_{Real}, N

Output: $E^i_{F,A,-}$, $E^i_{F,A,+}$, $P^i_{F,A,-}$, $P^i_{F,A,+}$

Define: *N* – Number of batteries

Define: $P^i_{F,A,+} = 0$, $P^i_{F,A,-} = 0$, $E^i_{F,A,+} = 0$, $E^i_{F,A,-} = 0$

$for\ (i = 1\ to\ N)$ (Asset Counting Loop) do

$P^i_{F+} = P^i_N + |P^i_{Measured}|$

$P^i_{F-} = P^i_N - |P^i_{Measured}|$

$E^i_{F-} = SOC^i_{F;MAX} * E^i_N - SOC^i_{F;Measured} * E^i_N$

$E^i_{F+} = SOC^i_{F;Measured} * E^i_N - SOC^i_{F;MIN} * E^i_N$

$P^i_{F,A,+} = P^i_{F,A,+} + P^i_{F+}$

$P^i_{F,A,-} = P^i_{F,A,-} + P^i_{F-}$

$E^i_{F,A,+} = E^i_{F,A,+} + E^i_{F+}$

$E^i_{F,A,-} = E^i_{F,A,-} + E^i_{F-}$

$end\ for$

6.5.2 Algorithm Dispatcher – Flex Disaggregation

Input: P_F, P^i_{Real}, P^i_{F+}, $P^i_{F,A,-}$, $P^i_{F,A,+}$

Output: $P^i_{F;S}$

Algorithm:

Define: $P_{REST} = 0$;

$\boldsymbol{for}\ (i = 1\ to\ N)$ (Asset Counting Loop) do

if (P_F = 0) ***then*** **–** *Case no adjustment of load or feed is necessary*

for *(i = 1 to N)* do

$P^i_{F;S} = P^i_{Measured}$

end for

end if

if (P_F < 0) ***then*** **–** *Case increase of load or decrease of feed is requested*

for *(i = 1 to N)* do

P1 = P^i_{F+} - $|P_F|$

if ($P1$ > 0) ***then***

$P^{i}_{F;S} = P^{i}_{Measured} - |P_F|$

$|P_F|$ = 0

Else

$P^{i}_{F;S} = P^{i}_{Measured} - P^{i}_{F+}$

$P_{REST} = P_{REST} - P^{i}_{F+}$

$P^{i}_{F;S} =$

P_{REST} =

if (P_F > 0) ***then* - –** *Case decrease of load or increase of feed is requested*

$End\ if$

7 Conclusions

This deliverable presented the algorithms to be implemented in the German demonstrator of the Platone project. An updated version of the solution design of the ALF-C and field-test have been given. Motivation, logic and mathematical problem have been described for each Use Case in detail.

The mathematical formulation of the problem to be solved turned out to be very complex. During the implementation and field-test phase of UC 1 from M18 to M24, it is expected that further development and refinement of the algorithms will be necessary. In order to ensure a safe and reliable operation during the field-test phase, the algorithms will be tested on data sets and trained on exemplary data sets before the application on the physical assets.

8 List of Tables

9 List of Figures

10 List of References

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11 List of Abbreviations

Abbreviation	Term
ALF-C	Avacon Local Flex Controller
CEC	Citizen Energy Community
D	Deliverable
DEMI	Distributed Energy Management Initiative
DER	Distributed Energy Resources
DSO	Related Term
EMS	Energy Management System
GCC	Grid Control Center
IT	Information Technology
LBES	Local Battery Energy Storage
LEC	Local Energy Community
LV	Low Voltage
MV	Medium Voltage
KPI	Key Performance Indicator
PV	Photovoltaic
RES	Renewable Energy Sources
SOC	State of Charge
T	Task
TSO	Transmission System Operator
UC	Use Case
UI	User Interface
WP	Work Package

P	Active Power [kW]
P_{Peak}	Peak Active Power [kW]
P_{TG}	Total Generation from Renewables [kW]
P_{TC}	Total Household Consumption [kW]
P_{TEI}	Total Power Grid Export/Import [kW]
P_{TCB}	Total Charging/Discharging [kW]
$P_{TCB;MAX}$	Nominal Power Charge/Discharge (continuous) [kW]
$P_{F;TG}$ (t+24)	Forecast of Total Renewable Generation for 24h Ahead [kW]
$P_{F;TEI}$ (t+24)	Forecast total Grid Export/Import for 24h Ahead [kW]
SOC_{MAX}/SOC_{MIN}	Maximum/Minimum allowed State of Charge of CBES [%] *Cannot be higher than $SOC_{TCB;N}$ or lower $SOC_{TCB;N;Min}$.
SOC_{Start}/SOC_{End}	State of Charge at Beginning/Ending of Forecast Period [%]
t_{Start}; t_{End}	Real Time Point of Time of Start
$t_{Measurement, Start}$; $t_{Measurement, End}$	Point of Time of Start/End of Measurement
$t_{UC, Start}$; $t_{UC, Start}$	Point of Time of UC Start/End
$t_{F,Start}$; $t_{F,End}$	Point of Time of Start/End of Forecast Period
$t_{SOC\ Start}$; $t_{SOC\ End}$	Point of Time of SOC_{Start}/SOC_{End}
$t_{SOC;Start,;Begin}$; $t_{SOC,End,Begin}$	Point of Time at which Charging or Discharging has to Begin in order to reach SOC_{Start}/SOC_{End} at Point of Time of $t_{SOC\ Start}$; $t_{SOC\ Start}$
E_{GS}	Generation Surplus (Energy) [kWh] (Erzeugungsüberschuss)
E_{GD}	Generation Deficit (Energy) [kWh]