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WP 5

Observability

Deliverable 5.5

Observables within framework of Web-of-Cells concept

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The document makes comparative analysis of the observability levels across all Use Cases describing controls required for operation of Web-of-Cells doing mapping and defining common elements, especially on the component level, which is essential for practical implementation of the concept and its scalability.				

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Executive summary

One of the key pillars in the ELECTRA IRP vision is that the European 2020 goals are not achievable without radical changes in the existing power system control paradigm. In the course of the project a novel architecture concept for the future power system has been suggested and coined: the “Web-of-Cells”.

Accommodation of intermittent generation into the network and its reliable operation require a gradual evolution of the network structure and in particular improvement of its control, monitoring or observability. An ELECTRA Cell is a portion of the power grid able to maintain an agreed power exchange at its boundaries by using the internal flexibility of any type available from flexible generators/loads and/or storage systems. The total amount of internal flexibility in each cell shall be at least enough to compensate the cell generation and load uncertainties in normal operation.

In order to maintain frequency (balancing) and voltage control in the future power system, the WoC control scheme introduces six high-level use cases, which are:

- Inertia Response Power Control (IRPC)
- Frequency Containment Control (FCC)
- Balance Restoration Control (BRC)
- Balance Steering Control (BSC)
- Voltage Control (PVC)
- Post Primary Voltage Control (PPVC)

For these use cases 40 different observables have been identified with detailed specification of the technical requirements and classified on control topology levels (CTLs) from 0 to 3. Further grouping of these into clusters has helped to uncover and understand similarities between them and narrow the scope from about 40 observables to 11 clusters.

- Cluster A (Local ROCOF)
- Cluster B ("Equivalent" inertia time constant or “equivalent” moment of inertia)
- Cluster C ("Equivalent" inertia time constant setpoint or “equivalent” moment of inertia setpoint)
- Cluster D ("Equivalent" inertia time constant or “equivalent” moment of inertia of a cell or of a WoC)
- Cluster E ("Equivalent" inertia time constant setpoint or “equivalent” moment of inertia setpoint for a cell or a WoC)
- Cluster F (Centre-of-inertia frequency and related ROCOF)
- Cluster G (Tie-line power)
- Cluster H (Cell-level frequency observation)
- Cluster I (Voltage)
- Cluster J (Imbalance estimation)
- Cluster K (Grid impedance estimation)

In order to evaluate and make a proposal for possible physical implementation of the identified observables, these were mapped across all six Use Cases to the Smart Grid Architecture's (SGAM) functional and component layers. Combining knowledge from technical requirements from clustering with mapping to SGAM's functional and component layers it was proposed an assignment of components for all six use cases: IRPC, FCC, BRC, BSC, PVC and PPVC and a list of components was suggested.

Terminologies

The Table 1 below shows a selection of the key definitions, which have been used within ELECTRA project. Some of these were initially introduced in the preceding deliverable [1] and modified later on.

It is necessary to mention that several new terms and definitions have been introduced, which have been specifically developed for the scope of the ELECTRA project, or have a meaning which may differ from the commonly used meaning.

Table 1 - Key definitions in the ELECTRA project

Term	Definition
Control Aim	A concise statement describing the control purpose of a control loop.
Observable	A uniquely valued function of a number of measurable quantities in a physical system. An observable can be either a scalar or vector ("State Vector") that is calculated from measured (observed) values in the present or past.
Transition Time	Time for system response or system control loops to complete the transition from a stationary system state to the next stationary state, after a switching event occurs within a power system.
Control Time Scale	A characteristic Transition Time at which a control loop operates. In this document, the following Control Time Scales (CTS) are used: ● CTS_0: System response (5 s) ● CTS_1: Primary Level (30 s) ● CTS_2: Secondary Level (120 s) ● CTS_3: Tertiary Level (900 s)
System Input Signal	A (scalar or vector) signal that is input to the power system, in order to change the value of an observable. Time for system response or system control loops to complete the transition from a stationary system state to the next stationary state, after a switching event occurs within a power system.
Observable algorithm	A detailed description of (or reference to) a specific set of operations that convert measurable values into an observable.
Control Topology Level	A characteristic Topology Level at which a control loop operates. Here the following Control Topology Levels (CTLs) are used: ● CTL_0: Physical (single) Device Level ● CTL_1: Flexible (aggregate) Resource Level ● CTL_2: Cell level ● CTL_3: Inter-cell level
Balance Control	Control loops that control the cell balance which is defined as the aggregated power flow profiles over the tie-lines (i.e.> import/export profiles)
N.B: The definitions of "Balance Control" & "Voltage Control" comprise a generic physical description of the control challenge, which is both technology independent and voltage level independent. So these generic definitions can be applied to all power system technologies. such as AC, DC, and to all voltage levels HV, MV, LV, et cetera.	

Term	Definition
Cell	An ELECTRA Cell is a portion of the power grid able to maintain an agreed power exchange at its boundaries by using the internal flexibility of any type available from flexible generators/loads and/or storage systems. The total amount of internal flexibility in each cell shall be at least enough to compensate the cell generation and load uncertainties in normal operation.

Abbreviations

AC	Alternating Current
AMI	Advanced Metering Infrastructure
AVR	Automatic Voltage Regulator
BRC	Balance Restoration Control
BRP	Balance Responsible Party
BSC	Balance Steering Control
COIF	Centre of Inertia Frequency
CPFC	Cell Power Frequency Characteristic
CSO	Cell System Operator
CTL	Control Topology Level
CTS	Control Time Scale
DAQ	Data Acquisition
DOW	Description of Work
DSO	Distribution System Operator
DSOGI	Dual Second Order Generalised Integrator
EMS	Energy Management System
EU	European Union
EV	Electric Vehicle
FACTS	Flexible AC Transmission Systems
FCC	Frequency Containment Control
FIR	Finite Impulse Response
FLL	Frequency Locked Loop
H	Inertia Constant
HV	High Voltage
ICT	Information and Communication Technology
ID	Identification
IED	Intelligent Electronic Device
IIR	Infinite Impulse Response
IRP	Integrated Research Program

IRPC	Inertia Response Power Control
LV	Low Voltage
MS	Milestone
MV	Medium Voltage
NPFC	Network Power Frequency Characteristics
OLTC	On-load Tap Changer
OPF	Optimal Power Flow
PDC	Power Distribution Centre
PDC	Phasor Data Concentrators
PLC	Power Line Carrier
PLL	Phase Locked Loop
PMU	Phasor Measurement Unit
PPVC	Post-Primary Voltage Control
PV	Photo Voltaic
PVC	Primary Voltage Control
RES	Renewable Energy Sources
RMS	Root-Mean-Square
ROCOF	Rate-Of-Change-Of-Frequency
SCADA	Supervisory Control And Data Acquisition
SRPS	Single Reference Power System
TSO	Transmission System Operator
tVPP	technical Virtual Power Plant
UC	Use Case
VSM	Voltage Stability Margin
WAMS	Wide Area Management System
WoC	Web-of-Cells
WP	Workpackage

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1 Introduction

1.1 Assumptions and limitations of the study

The overall objective of the ELECTRA project is to develop radically new control solutions for 2035 and beyond. Expectations and scenarios for a future with such a relatively distant time horizon will inevitably contain a substantial amount of uncertainty. Even though the work package has tried to mitigate the overall uncertainty, relating to the publicly available roadmaps for the near future it is still necessary to make several assumptions in order to handle these future uncertainties. The following main assumptions have been made:

- Some of the identified observability needs may not be met in the course of the project, but nonetheless are expected to be achievable in due time.
- Technology limitations are not considered. Considering the rapid development during recent years in technologies such as communications and computation, and the long-time horizon that is being considered within the project. Technologies not feasible now could well be developed in near future, thereby enabling control solutions that seem unrealistic right now. However, present technological limitations will be taken into account to ensure that progress can be achieved.
- Cost limitations are not considered. Technological advancement normally leads to significant cost reductions.
- Potential conflicts between different control schemes are not considered. These are planned to be addressed more specifically in another ELECTRA deliverable. Therefore, the present Task does not omit any control schemes due to potential conflicts between these.

ELECTRA IRP is a big interdisciplinary project with several ongoing parallel and complementary activities. Several conceptual ideas and definitions have been constantly evolving during the course of the project, making it difficult to avoid some minor discrepancies between terms and definitions, which this report refers to.

The activity makes mapping of observables to several layers of Smart Grid Architecture Model (SGAM) using the framework and definitions provided in [2]. Mapping of some elements in particular related to the communication structure may depend upon specific implementation and size of a given cell (-s).

Doing mapping on both functional and component levels it is necessary to consider elements, related to communication infrastructure even though they are out of scope for the present workpackage. Furthermore, the task does not focus on standards, security and communication protocols, which have been addressed in another Electra deliverable (see [3]).

The main objective of this report is to make a comparative analysis of the observability levels across all Use Cases describing controls required for operation of Web-of-Cells doing mapping and defining common elements, especially on the component level, which is essential for practical implementation of the concept and its scalability.

1.2 Outline of report

The document begins with reference to the main objectives in Section 2, followed by a brief description of a novel concept for the future power system's architecture, which has been suggested and developed within ELECTRA IRP – the Web-of-Cells (WoC). The section also presents six high-level use cases describing the new balance and voltage controls, which are essentially the cornerstone for Web-of-Cells.

The following Section 3 reminds the main elements of the measurement chain and data acquisition procedure and continues with explanation of technical criteria, which were used for extraction of all observables from the Use Cases and comparative mapping of these in tabular form.

Mapping of the observables of the Use Cases and further grouping of these into clusters has helped to uncover and understand similarities between these and narrow the scope from about 40 observables to 11 clusters and is presented in Section 4. The next Section 5 makes mapping of the observables across all six Use Cases to the Smart Grid Architecture's (SGAM) functional and component layers in order to evaluate and make a proposal for possible physical implementation of the identified observables. By the end of this section it was also made a combined mapping of components from all six Use Cases into one component layer, making a proposal for physical implementation of the concept.

Conclusions for the report are presented in Section 6.

2 Observability for the future power system

Accommodation of intermittent generation into the network and its reliable operation require a gradual evolution of the network structure and in particular improvement of its control, monitoring or observability.

Adequate observability of the power system operating state is among the requirements for a reliable and secure supply of electricity. In the past, operation of the conventional vertical "downfall" power system did not necessarily require excessive monitoring and observability, especially in the distribution network. Yet sufficient information and communication technologies have been in place for decades, but these were confined only to TSOs mostly due to economic reasons.

Because of the massive presence of decentralized and stochastic power sources, the required awareness for the future power system is expected to be much higher than at present. Reconsideration of system observables will therefore be needed as an input for control strategies during operation. From a technical point of view, strong support for increasing system observability will be gained from the further development of ICT and their integration as a new layer into the electricity network, in particular at the distribution level, to obtain the so-called smart grids.

The main objective of the ELECTRA activity "Observability is therefore to develop and implement adequate concepts and methods for sufficiently observing the state of the future power system for the two axes:

- Pan-European
- Local (Horizontal/ Distributed)

In the course of the project's execution it has been decided to focus on the development of related observables on the horizontal integration.

The ELECTRA activity on "Observability" included the following tasks:

- Adaptive assessment of future scenarios and mapping of observability needs
- Observables for Distributed Local Control Schemes
- The ELECTRA WoC concept – A control architecture specification for operating the power system 2035+
- Observables for Pan-European Control Schemes
- Comparative analysis and enabling global level design (the present activity)

2.1 Web-of-Cells concept - solving local problems locally

In the future grid, a scenario shift is expected from large central synchronous generators at the transmission level to smaller, and usually intermittent (such as PV panels, wind turbines), production units at the distribution level, which cannot participate directly in central balancing by the TSO and do not provide inertial response power for instantaneous balancing. Furthermore, coincident non-intermittent loads like EV (Electric Vehicle) battery charging stations and heat pumps may cause temporary overloads in LV and MV substations and lines.

In the course of the project a novel architecture concept for the future power system has been suggested (for details see [4]). This concept was coined the “Web-of-Cells”.

2.2 Web-of-Cells in a nutshell

ELECTRA introduced the Web-of-Cells (WoC), which is a cell-based architecture for decentralized balancing (frequency) and voltage control. The ELECTRA activity foresees the future power system as split into a WoC structure, where each cell is defined as follows see [5]).

An ELECTRA Cell is a portion of the power grid able to maintain an agreed power exchange at its boundaries by using the internal flexibility of any type available from flexible generators/loads and/or storage systems. The total amount of internal flexibility in each cell shall be at least enough to compensate the cell generation and load uncertainties in normal operation.

In line with the above definition:

- an ELECTRA Cell is connected to one or more neighbouring cells via one or more physical tie-lines
- there is no restriction in how cells are interconnected
- an ELECTRA Cell can span one or more voltage levels
- it is not required that a cell is self-sufficient (capable to balance internal generation and load), but this case is possible

The system-level defined cell balance setpoints prescribe the expected/agreed/cleared cell power flow exchange profiles with neighbouring cells. These setpoints are the result of a system-level optimal market clearing process, based on (cell) location aware generation and (flexible) load forecast information.

Each cell is managed by a so-called Cell Controller (CC). The CC is under the responsibility of a Cell System Operator (CSO) role that supervises its operation and, if needed, is able to override it. A Cell System Operator (like present DSOs/TSOs) can operate multiple CC and therefore operate more cells also non-adjacent.

Optionally: Like microgrids, cells can be equipped with functionality to disconnect/reconnect them from/to the main grid. Such islanding functionality can be used to either isolate ‘bad’ cells to prevent infection of the main grid, or to isolate ‘good’ cells from a ‘bad/unreliable’ main grid.

ELECTRA cells use the flexibility of their internal energy resources (mainly flexible loads and storage) to autonomously maintain the scheduled total power exchange with neighbours. They use detailed local grid information to do this in the most effective and grid secure manner, and to avoid local congestion or voltage problems.

Using the above WoC definition, the following specific characteristics can be observed:

- Voltage and balancing problems are usually solved within a cell where observables are used to decide on corrective actions to handle these local issues (i.e., localization and local empowerment).

- Communication complexity and latencies as well as computation complexity are minimized (i.e. "divide and conquer").
- Local grid conditions are explicitly taken into consideration when deciding what kinds of resources are used.
- A distributed bottom-up approach is provided for restoring system balance.
- Focus is more on balance restoration – and thereby frequency restoration as well - rather than the current traditional sequence of frequency containment followed by frequency restoration.

2.3 Web-of-Cell operation modes and related functions

In order to maintain frequency (balancing) and voltage control in the future power system, the WoC control scheme introduces six high-level use cases, which are:

- Inertia Response Power Control (IRPC)
- Frequency Containment Control (FCC)
- Balance Restoration Control (BRC)
- Balance Steering Control (BSC)
- Voltage Control (PVC)
- Post Primary Voltage Control (PPVC)

These use cases are characterized by three fundamental characteristics:

- Solving local problems at cell level
- Responsibilization with local neighbour-to-neighbour collaboration
- Ensuring that only local reserves providing resources will be used whose activation does not cause local grid problems.

Cells are treated as 'physical clusters' with characteristics of a Virtual Power Plant (VPP) responsible for matching their actual net active power import/export profile to the forecasted profile (which relates to system balance). This is the responsibility of the **Balance Restoration Control (BRC)** functionality. The system balance (as well as frequency) is restored according to a bottom-up approach based on local observables (cell tie-line power flows). The cell setpoints correspond to a system balance and if each cell adheres to its setpoint, the system balance is kept. The proposed BRC shows resemblance to the current Frequency Restoration Control (FRC) responsible for restoring the system balance and frequency, yet in a centralistic manner. In contrast to FRC, which is a secondary control and takes over from Frequency Containment Control (FCC), in the ELECTRA WoC concept the BRC runs at the same timescale as FCC and therefore contributes to frequency containment as well as balance/frequency restoration. Deviations observed by a cell can be caused by the cell itself, but also by neighbouring cells, so there is a level of local collaborative balance (and frequency) restoration.

For **Frequency Containment Control (FCC)** an adaptive functionality is proposed. It ensures that each cell adapts the amount of provided dP/df droop in response to real-time frequency and tie-line deviations from their nominal values. The output of this process is used as a multiplication coefficient for the nominal Cell Power Frequency Characteristic. The latter parameter is specified by a setpoint received from a system-level process. A cell central Frequency Droop Parameter Determination function receives the cell's CPFC setpoint (cell's contribution to the system NPFC – Network Power Frequency Characteristics) for the next timestep. The Merit Order Decision function ranks the available frequency droop devices based on cost and location. This is done based on availability and cost information received from these frequency droop devices, load and generation forecasts of all busses (nodes), and a local grid model. Location information is important to ensure that the power activations of the Frequency Droop devices will not cause local grid problems. The resulting ordered list is sent to the Frequency Droop Parameter Determination function determining the requested dP/df droop setting (which can also be 0) for each frequency droop device. Each frequency droop device receives its droop setting (droop slope and deadband) for the next timestep, and will continuously monitor df and change its active power injection/absorption in accordance to its droop setting. This droop setting is continuously adapted by the adaptive CPFC determination function by means of a scaling factor determined based on the cell's imbalance state. Based on frequency and cell imbalance error signals, this function will calculate a scaling factor to achieve that most FCC activations are done in cells actually causing the deviation. This should mitigate the effect of causing cell imbalances (with subsequent BRC activations) in cells that otherwise would be in balance because of a blind reaction on a global observable (frequency deviation). This is the adaptive aspect. In contrast to 'traditional' frequency control, this adaptive FCC is not a primary response followed by a slower secondary response taking over from this primary response: Instead, it runs at the same timescale as the Balance Restoration Control and both join forces in containing frequency deviations.

As mentioned above, more and more grid integrated distributed electricity generation is going to be converter based. All photovoltaic power plants as well as a high share of wind power plants already use converters as grid interfaces. Hence, the contribution of synchronous generators providing inertia through their rotating mass is expected to decline. Based on the actual energy mix the available inertia can vary wildly. For that reason, ELECTRA IRP has introduced an **Inertia Response Power Control (IRPC)** functionality, which ensures additional synthetic inertia is supplied (by managing suitable flexible resources), to complement the physical inertia left in the system. A cell central df/dt droop slope determination function receives a cell's J (moment of inertia) setpoint (cell's contribution to the system inertia) for the next timestep. A merit order decision function ranks the available required rate of change of frequency (ROCOF) droop devices based on cost and location. This is done based on availability and cost information received from these ROCOF droop devices, load and generation forecasts of all busses (nodes), and a local grid model. As already remarked for FCC, location information is important to ensure that power activations of the ROCOF droop devices will not cause local grid problems. The resulting list is sent to the df/dt droop slope determination function that defines the requested df/dt droop slope setting (which can also be 0) for each ROCOF droop device. Each ROCOF droop device receives its droop setting for the next timestep, and will continuously monitor df/dt and change its power injection/absorption in accordance to its droop setting. No deadband will be used so that an action is taken even on the slightest variation of $\Delta f/\Delta t$. This choice is made to reap the side-effect of limiting the frequency fluctuation also during normal operation; i.e. the frequency fluctuation due to small variations of load and generation. A deadband combined with a low amount of inertia provided by synchronous generators could result in high frequency fluctuation tripping some of the connected generation. IRPC functions are to be coordinated with FCC and BRC functions as hinted at in [6].

To complete the Balance/Frequency Control related functionalities a **Balance Steering Control (BSC)** is introduced. The BSC tries to counteract the excessive amount of bottom-up BRC activations based on local observables and the lost benefits of imbalance netting. BSC implements a distributed/decentralized coordination scheme where neighbouring cells mutually agree on changing their tie-line active power flow setpoints – without violating operating limits - and this way reduce the amount of BRC reserves that would be activated in each cell. This can be considered as an implementation of a localized imbalance netting mechanism. Specifically, this use case will implement a corrective BSC functionality, which determines new setpoints for the BRC controller, thereby causing the deactivation of resources previously activated by BRC.

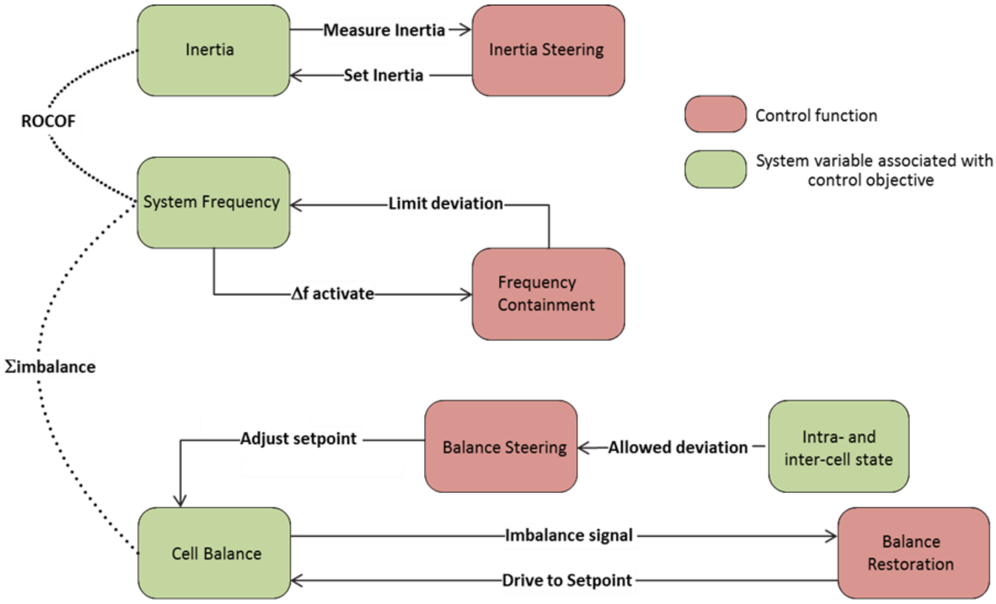

Figure 1 - Web-of-Cell balance control functions

Voltage control functions (see Figure 2) are active at all voltage levels in a very dynamic manner: not only to correct voltage deviations that cause voltage limit violations, but to minimize power-flow losses too. The **Primary Voltage Control (PVC)** functionality, as it is already in use today, will be present at all voltage levels.

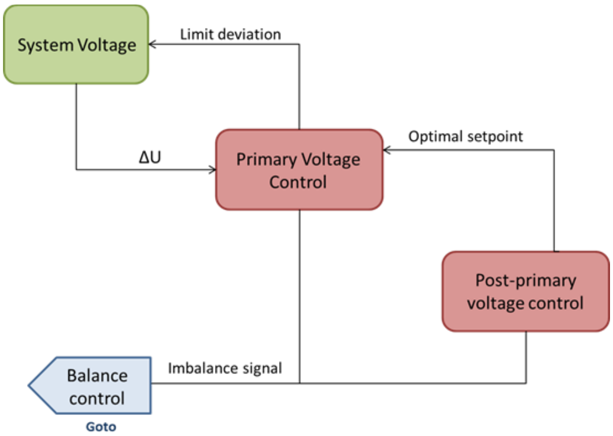

Figure 2 - Web-of-Cell voltage control functions

Additionally, ELECTRA proposes **a Post-Primary Voltage Control (PPVC)** functionality determining setpoints for all resources able to contribute to voltage control (and loss minimization): like PVC (automated voltage regulation)-resources, Q-controllable resources, tap-changing transformers, capacitor banks. The cell central PPVC function is activated either by means of a system level trigger (proactive setpoint recalculation), or when one of the pilot nodes reports a voltage violation (i.e. a voltage deviation outside the limits: corrective setpoint recalculation). ELECTRA assumes there is no constant polling by the PPVC function of all pilot nodes, but that pilot nodes autonomously monitor their local voltage and send a signal when they detect a violation. On receipt of the activation trigger (timer or voltage violation error), the PPVC function will send a trigger signal to the PPVC setpoint providing function to initiate the calculation of new setpoints. As input for this setpoint calculation, information is collected from the (voltage) reserves information provider function (availability of voltage reserves), the tie-line power flow setpoint provider function (reactive power-flow profile setpoint at the cell tie-lines), and the load &

generation forecast providing function (load and generation forecasts). For implementing this functionality, a local grid model is assumed to be available. Based on all this information, the PPVC setpoint providing function performs an Optimal Power Flow (OPF) to calculate voltage setpoint settings keeping all nodes within the limits according to valid standards and minimizing power flow losses in the cell. The PPVC control function then sends the calculated setpoints to the PVC droop nodes, controllable Q nodes, capacitor banks and on-load-tap-changer-transformers (OLTCs).

3 Mapping and comparison of the Observables from the Use Cases (Tables)

The Web-of-Cells concept, suggested by ELECTRA IRP is based on operation of six control schemes, which include:

- Balance Control:
    - IRPC - Inertia Response Power Control
    - FCC - Frequency Containment Control
    - BRC - Balance Restoration Control
    - BSC - Balance Steering Control
- Voltage Control:
    - PVC – Primary Voltage Control
    - PPVC – Post-Primary Voltage Control

Within ELECTRA IRP those schemes were suggested and developed into a set of dedicated Use Cases, which were further elaborated and seriously modified during the project (see [6] for detailed description). Furthermore, these UCs were implemented and tested by the partners in simulation and lab environments (see [7] for results and conclusions). A real operational Web-of-Cells requires that all these controls will function simultaneously within each cell. However due to limitations of the present project, the implementations and tests were essentially done for single UCs within activity “Control Schemes for use of Flexibility” and combination of UCs were dealt within activity “Integration and Lab Testing”. It is however necessary to have a closer look on observables across all Use Cases in order to identify similarities and overlaps.

3.1 The measurement chain

The previous report in this activity [8] described functionality of the measurement chain, which in general includes three major components as it is presented in Figure 3. For detailed description see Annex in [8].

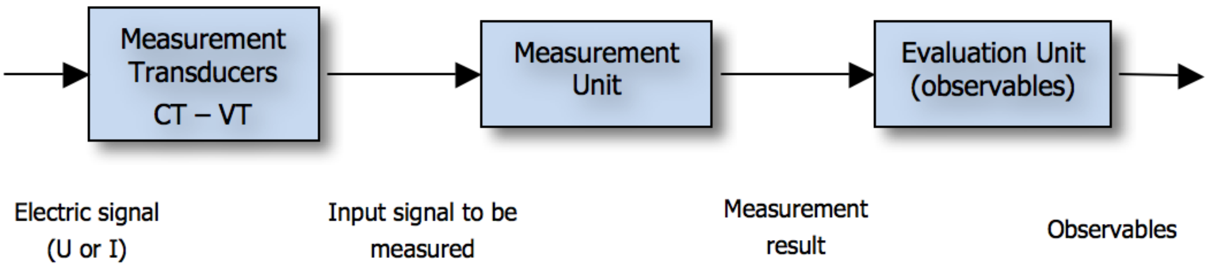

Figure 3 - The measurement chain

The electrical quantity to be measured may be either directly accessible, as is generally the case in low voltage systems, or accessible via measurement transducers like measurement transformers.

These transducers are needed to step down the voltage, to isolate the input circuits from the system voltage, or to transmit the signals over some distance. To accomplish any of these functions, the characteristics of the transducer must be suitable for the variable of interest, the current or the voltage. An "instrument" may include the whole measurement chain or a part of it.

3.2 Data acquisition

Data acquisition is the process of sampling signals that represent measurements of physical variables (i.e. voltage and current) and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems typically convert analogue waveforms into digital values for processing, see Figure 4. The components of data acquisition systems include:

- Sensors that convert physical variables to electrical signals
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values
- Analogue-to-digital converters, which convert conditioned sensor signals to digital values

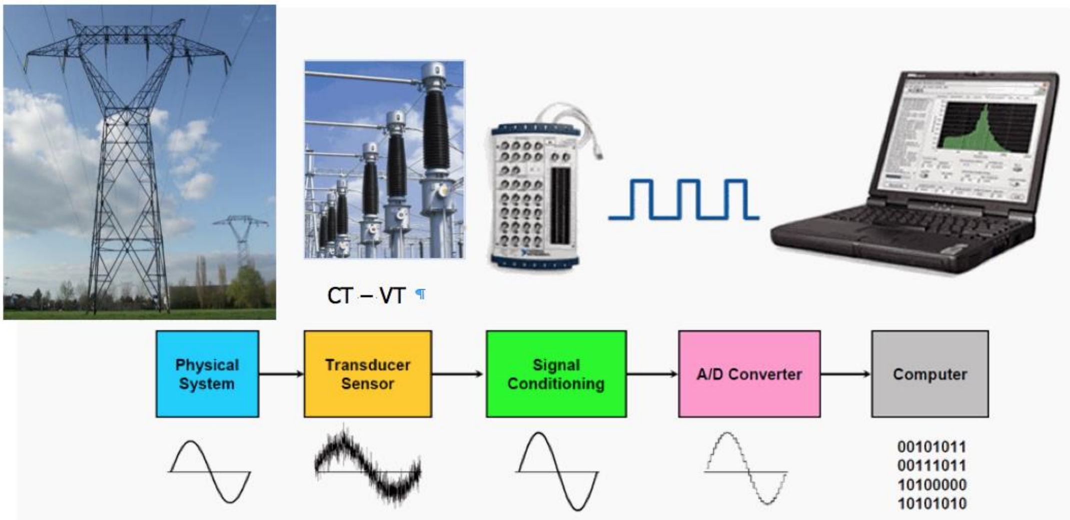

Figure 4 - Data acquisition

The transducers are the measurement transformers that convert the electrical MV or HV signals (voltage and current) into a corresponding smaller signal, which will be handled by the acquisition system. This acquisition system depends on the characteristics of the secondary signals of the measurement transformers. For example, the secondary current given by the CT will be converted into a voltage signal that will be easily handled by the A/D converter. Signal conditioning may be necessary if the signal from the transducer is not suitable for the Data acquisition (DAQ) hardware being used. The signal may need to be filtered or amplified in most cases. The analogue-to-digital converter or A/D converter is the device that converts a continuous physical quantity (usually a voltage) to a digital number that represents the quantity amplitude (voltage and current).

3.3 Criteria for mapping of the observables

The mapping uses the UCs descriptions from [6], which is also used by all other tasks in the project. The observables have been mapped and classified across different categories and technical requirements.

- Observable
- Use Case, where the observable is applied
- Similar observables, which can be grouped (ID nr)

- Function(s) in the UC, in which the observable is employed
- Control Topology Level (CTL) for the measurement
- Control Time Scale (-s) (CTSs)
- Control aim (of function)
- Observable input signal(s)
- Observable algorithm description, reference
- Minimum time resolution for the input (sample frequency)
- Minimum time resolution for the output (sample frequency)
- Time resolution tested/implementation (sample frequency)
- Maximum latency value required by the control (delay in measurement, computation, transmission etc.)
- Actual latency caused by the observable algorithm
- Actual latency tested (consider including reference to the actual implementations)
- Reference location according to the network's voltage level (LV/MV/HV)
- Reference location according to the network's topology
- Possible input device /component
- Time stamp (yes/no) Maximum accuracy
- Actual accuracy
- Requirements to the communication channel
- Is the observable communicated to another use case or component? (yes/no; if yes, to which use case/component?)
- Commonly used/regular practice observable (yes/no)

Altogether, 40 different observables have been identified, and classified on control topology levels (CTLs) from 0 to 3. The overall mapping is presented in tabular form in Table 14 - Table 16 in Annex 1.

4 Clusters of the observables

The idea of clustering is based on the assumption that in several cases observables can be generated based on metered values (input signals) obtained from the same measuring device, as for example in PVC and PPVC. Several observables can be obtained from a measuring device installed on the same control topology level CTL-0 and the same place in the network, in particular at the same bus. A main difference can be how often the measurements have to be acquired from the given device, e.g. every second or every 15 minutes (for explanation of Control Time Scales see Table 1).The clustering has been based on the tables of the mapped observables from the previous section (see Annex I, Table 14).

The clustering has been done by grouping the observables according to the following parameters: applied Control Topology Level (CTL) (see Table 1), Observable input signal (-s) and (when possible) Input Device/component. Table 14 shows how similar observables were combined into clusters in column " Similar observables, which can be grouped".

For the sake of simplicity, each cluster received an identifier – capital letters from A to K were assigned as identifiers to eleven clusters have been defined.

1. Cluster A (Local ROCOF)
2. Cluster B ("Equivalent" inertia time constant or “equivalent” moment of inertia)
3. Cluster C ("Equivalent" inertia time constant setpoint or “equivalent” moment of inertia setpoint)

4. Cluster D ("Equivalent" inertia time constant or “equivalent” moment of inertia of a cell or of a WoC)
5. Cluster E ("Equivalent" inertia time constant setpoint or “equivalent” moment of inertia setpoint for a cell or a WoC)
6. Cluster F (Centre-of-inertia frequency and related ROCOF)
7. Cluster G (Tie-line power)
8. Cluster H (Cell-level frequency observation)
9. Cluster I (Voltage)
10. Cluster J (Imbalance estimation)
11. Cluster K (Grid impedance estimation)

ID nr	IRPC_01	IRPC_02	IRPC_03	IRPC_04	IRPC_05	IRPC_06	IRPC_07	IRPC_08	IRPC_09	IRPC_10	IRPC_11	IRPC_12	IRPC_13	IRPC_14	FCC_01	FCC_02	BRC_01	BRC_02	BRC_03	BSC_01	BSC_02	BSC_03	BSC_04	PVC_01	PVC_02	PPVC_01	PPVC_02	PPVC_03
IRPC_01	A	A																										
IRPC_02	A	A																										
IRPC_03			B	B	B																							
IRPC_04			B	B	B																							
IRPC_05			B	B	B																							
IRPC_06						C	C	C																				
IRPC_07						C	C	C																				
IRPC_08						C	C	C																				
IRPC_09									D	D																		
IRPC_10									D	D																		
IRPC_11											E	E																
IRPC_12											E	E																
IRPC_13													F	F														
IRPC_14													F	F														
FCC_01															G		G		G				G					
FCC_02																H		H			H	H						
BRC_01															G		G		G				G					
BRC_02																H		H			H	H						
BRC_03															G		G		G				G					
BSC_01																				J								
BSC_02																H		H			H	H						
BSC_03																H		H			H	H						
BSC_04															G		G		G				G					
PVC_01																								I		I	I	I
PVC_02																									K			
PPVC_01																								I		I	I	I
PPVC_02																								I		I	I	I
PPVC_03																								I		I	I	I

Figure 5 - Clustering of the observables

Figure 5 depicts clustering in a matrix form, where the IRPC Use Case includes six, Voltage Control UCs include together two and three clusters are scattered around three UCs, namely FCC, BRC and BSC, due to the fact that these UCs share a more or less common group of observables; PVC and PPVC involve two clusters. It is also worth noting that, among other observables, BSC uses the value of the BRC output for imbalance estimation, a parameter not used by other UCs, thus making up a cluster of one single observable.

The following sections makes a more detailed presentation of each of the clusters.

4.1 Cluster A (Local ROCOF)

4.1.1 Description of the cluster

This cluster refers to the local observation of the ROCOF, carried out continuously in time at the single device level (CTL0) and/or at the aggregated device level (CTL1). This is used in the IRPC UC, in that the related virtual inertial response, in terms of a power injection/absorption variation by the device and/or by the aggregated devices, will be proportional to the observed ROCOF and it will be delivered continuously in time (the corresponding reference time scale is CTS-0).

4.1.2 The cluster's technical requirements

The technical requirements are presented in Table 2.

Table 2 - Technical requirements for Cluster A (Local ROCOF)

Type	Value	Comments
The input signal	Voltage waveform	
The output signal	Frequency gradient df/dt (ROCOF)	
Required time resolution (sampling frequency)	1000 Hz at least for the input signal, 50 Hz at least for the output signal	General comment: x Hz means x samples per second
Time stamp	Yes	
Maximum latency allowed (including the communication part)	from <100 ms up to 500 ms	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	LV/MV/HV, i.e. both transmission and distribution	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Field	
Accuracy	0.1-1 mHz/s	

4.1.3 Possible implementation

In practice, the observation of the ROCOF can be implemented via PLL (or FLL) and IIR derivative observer functions, if necessary in combination with a voltage measurement transformer.

4.2 Cluster B ("Equivalent" inertia time constant or "equivalent" moment of inertia)

4.2.1 Description of the cluster

This cluster is used in the IRPC UC. The term "equivalent" is adopted in order to be able to refer both to the amount of *physical* inertia which characterizes a rotating machine or a whole conventional power plant, and to the amount of *synthetic* inertia, which can be supplied by a DER or a set of aggregated devices connected to the transmission or distribution grid via power electronic converters. Inertia can be expressed via a time constant (H) or a moment of inertia (J) (alternatively, one can use kinetic energy, usually expressed in MW·s). Such information can be sent to the cell operator (i.e. to CTL-2) at every CTS-3 time slot, so that it can decide how much of the available inertia should be deployed in the next time slot. More precisely, a merit order decision function can be adopted at CTL-2 by the cell operator, to make a ranking of the available ROCOF droop devices (each endowed with its equivalent inertia time constant or equivalent moment of inertia), based on cost and location, and to decide which devices to activate to supply inertial response power in the next time slot.

4.2.2 The cluster's technical requirements

The cluster's technical requirements are presented in Table 3.

Table 3 - Technical requirements for Cluster "Equivalent" inertia time constant

Type	Value	Comments
The input signal	No input required	
The output signal	H or J	This information is among the plant/device nameplate data or among its operational (or market) data. E.g., the inertia constant or J of a machine is related to its nominal power or to its rotating mass; the fictitious inertia constant of an electronic device can be determined from how much power it is able to supply against a certain df/dt value
Required time resolution (sampling frequency)	CTS-3	
Time stamp	Not required	
Maximum latency allowed (including the communication part)	CTS-3	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	LV/MV/HV, i.e. both transmission and distribution	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Field	
Accuracy	- 0.1 s or less - fractions of 0.01 MW s^2	- Since H for conventional plants is of the order of some seconds - Compare the order of magnitude of J for conventional machines

4.2.3 Possible implementation

The information about the current value of equivalent H or J available in each plant or device or aggregation of devices should be transmitted by the device/devices itself/themselves to the cell operator, via a suitable ICT channel or device, at prescribed time intervals consistent with the CTS-3 time scale. In case the value to be transmitted is a nameplate figure, it can be transmitted only in case it varies due to a change of plant configuration or plant hardware modification. In case it is related to the device operating conditions, it can be measured locally, e.g. via prescribed standardized procedures, and then sent to the cell operator (or to the centralized ranking function mentioned in Section 4.2.1).

4.3 Cluster C ("Equivalent" inertia time constant setpoint or “equivalent” moment of inertia setpoint)

4.3.1 Description of the cluster

This cluster is used in the IRPC UC. It refers to the amount of physical inertia to be deployed by a rotating machine or conventional power plant and to the amount of synthetic inertia to be deployed by a DER or a set of aggregated devices connected to the transmission or distribution grid via power electronic converters. Each such amount of inertia can be expressed via a time constant (H) or a moment of inertia (J), or also via an energy value (in MWs). Its value is determined by the cell operator (i.e. to CTL-2) at every CTS-3 time slot thanks to a merit order function, it and is sent to individual or aggregated devices as a setpoint to be set inside their ROCOF droop controller, to supply inertial response power in the next time slot.

4.3.2 The cluster’s technical requirements

The technical requirements are presented in Table 4.

Table 4 - Technical requirements for cluster C ("Equivalent" inertia time constant setpoint)

Type	Value	Comments
The input signal	No input required	
The output signal	H or J	This output comes from an optimization function or a decision taken by the cell operator
Required time resolution (sampling frequency)	CTS-3	
Time stamp	Not required	
Maximum latency allowed (including the communication part)	CTS-3	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	LV/MV/HV, i.e. both transmission and distribution	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Field	
Accuracy	- 0.1 s or less - fractions of 0.01 MW s^2	- Since H for conventional plants is of the order of some seconds - Compare the order of magnitude of J for conventional machines

4.3.3 Possible implementation

The output H or J to be sent, as a setpoint to be enforced/tracked by local control, to machines and devices comes from an optimization function or a decision taken by the cell operator, so there is no measurement algorithm or device behind this kind of observable.

4.4 Cluster D ("Equivalent" inertia time constant or “equivalent” moment of inertia of a cell or of a WoC)

4.4.1 Description of the cluster

This cluster is used in the IRPC UC and it is similar to cluster B (see Section 4.2), but at a higher topological level: It refers to the overall amount of physical and synthetic inertia which can be supplied by a cell or by the whole WoC. Such amount for a cell or for a WoC is part of the cell or WoC operational data; It can be expressed via a time constant (H) or a moment of inertia (J) or an energy value and it is needed as an input in an "equivalent" inertia procurement process carried out by the synchronous area (i.e. at CTL-3) inertia controller to collect enough equivalent inertia within a cell or WoC for ROCOF containment within the WoC. The information can be collected at every CTS-3 time slot or on even much slower time scales (an hour, a day, a week, a month, a year).

4.4.2 The cluster’s technical requirements

The requirements are presented in Table 5.

Table 5 - Technical requirements for cluster D ("Equivalent" inertia time constant or “equivalent” moment of inertia of a cell or of a WoC)

Type	Value	Comments
The input signal	No input required	
The output signal	H or J	This information is among the cell/WoC characteristic data (if one considers the maximal amount of inertia) or among its operational (or market) data
Required time resolution (sampling frequency)	CTS-3 or slower	To be decided by the WoC coordination or by the synchronous area inertia controller (as a part of the WoC coordination mechanisms)
Time stamp	Not required	
Maximum latency allowed (including the communication part)	CTS-3 or more	See the “Required time resolution” slot
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	Not necessarily specified: LV/MV/HV, i.e. both transmission and distribution	This location depends on the cell(s) topology and boundaries, anyway it is not specific, but it refers to a whole WoC or to a whole synchronous area
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Operation, Market	
Accuracy	- 0.1 s or less	- Since H for conventional plants is

Type	Value	Comments
	- fractions of 0.01 MW s^2	of the order of some seconds - Compare the order of magnitude of J for conventional machines

4.4.3 Possible implementation

The information about the current value of the equivalent H or J available in a cell or in a whole WoC and to be sent to the overall inertia controller for inertia procurement can be considered roughly as the sum of all the H or J values coming from the individual plants, the individual devices and the aggregations of devices which are available for equivalent inertia supply in the cell or in the WoC. Thus, since the devices/aggregations themselves should transmit their information to the cell operator, via a suitable ICT channel or device, at CTS-3 time intervals for instance (see Section 4.2.3), then this information should already be available to be sent to the WoC coordination mechanism or to the synchronous area controller.

4.5 Cluster E ("Equivalent" inertia time constant setpoint or “equivalent” moment of inertia setpoint for a cell or a WoC)

4.5.1 Description of the cluster

This cluster is used in the IRPC UC and it is similar to cluster C (see Section 4.3), but at a higher topological level: it refers to setpoint of overall amount of physical and synthetic inertia to be deployed by a cell or by the whole WoC. This setpoint is the output of the "equivalent" inertia procurement process aimed at ROCOF containment within a WoC, carried out by the WoC or by the synchronous area inertia controller, i.e. at CTL-3. Again, the setpoint amount of inertia can be expressed via a time constant (H) or a moment of inertia (J). Its value is determined/decided at time intervals which can be CTS-3 or longer.

4.5.2 The cluster’s technical requirements

The technical requirements are presented in Table 6.

Table 6 - Technical requirements for Cluster E ("Equivalent" inertia time constant setpoint or “equivalent” moment of inertia setpoint for a cell or a WoC)

Type	Value	Comments
The input signal	No input required	
The output signal	H or J	This output comes from an optimization function or a decision taken by the WoC coordination or by the synchronous area inertia controller
Required time resolution (sampling frequency)	CTS-3 or slower	To be decided by the WoC coordination or by the synchronous area inertia controller (as a part of the WoC coordination mechanisms)
Time stamp	Not required	

Type	Value	Comments
Maximum latency allowed (including the communication part)	CTS-3 or more	See the “Required time resolution” slot
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	Not necessarily specified: LV/MV/HV, i.e. both transmission and distribution	This location depends on the cell(s) topology and boundaries, anyway it is not specific, it refers to a cell or to a whole WoC
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Operation, Market	
Accuracy	- 0.1 s or less - fractions of 0.01 MW s^2	

4.5.3 Possible implementation

The output H or J to be sent to one or more cell operators (at CTL-2), as a setpoint to be enforced/tracked by a cell or a WoC, comes from a cell or WoC optimization function or a decision taken by the cell coordination mechanism or by the synchronous area controller, so there is no measurement algorithm or device behind this kind of observable, but a suitable dedicated transmission channel can be needed, as it happens for cluster D.

4.6 Cluster F (Centre-of-inertia frequency and related ROCOF)

4.6.1 Description of the cluster

This cluster is used in the IRPC UC and it includes observables which can be adopted both for monitoring purposes, e.g. to check continuously that IRPC is effective, and as a support for the decision/computation process related to cluster E (see Section 4.5), i.e. for the determination of the equivalent inertia setpoint for a cell or for a WoC. The involved observables are the Centre-Of-Inertia Frequency (COIF) and the related ROCOF, i.e. the COIF time derivative. They can usually be associated to a cell (CTL-2) and they are derived (as weighted averages e.g.) from frequency and/or ROCOF values measured locally (in one or more selected nodes, similar to voltage control pilot nodes) and continuously in time (the corresponding reference time scale is CTS-0).

4.6.2 The cluster’s technical requirements

The technical requirements are presented in Table 7.

Table 7- Technical requirements for cluster F (Centre-of-inertia frequency and related ROCOF)

Type	Value	Comments
The input signal	Voltage waveform	
The output signal	Frequency and frequency gradient df/dt (ROCOF)	
Required time resolution (sampling frequency)	1000 Hz at least for the input signal, 50Hz at least for the output signal	

Type	Value	Comments
Time stamp	Yes	
Maximum latency allowed (including the communication part)	from <100 ms up to 500 ms	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	LV/MV/HV, i.e. both transmission and distribution	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Field	
Accuracy	1 mHz 0.1-1 mHz/s	

4.6.3 Possible implementation

In practice, the observation of the frequency values yielding the COIF and the observation of the ROCOF related to the COIF can be implemented via PLL (or FLL) and IIR derivative observer functions, if necessary in combination with voltage measurement transformers.

4.7 Cluster G (Tie-line power)

4.7.1 Description of the cluster

The cluster consists of tie-line power measurements used in both FCC, BRC and BSC. The measurements are all performed at cell level (CTL-2), however, the CTS levels differs between the use cases: CTS-0 for the Tie-line power measurement used in the FCC Imbalance observation function, CTS-1 for the Tie-line power measurement used in the BSC Imbalance observation function and CTS-2 for the Tie-line power measurement used in the BRC Imbalance observation function. The CTS level is reflected of the response time of the respectively use case.

The Imbalance observation function collects and aggregates the tie-line observables and compares this against the cell setpoint to determine a cell balance error signal. The function is applied in BRC, where the results is used as input to the imbalance correction function. The results is also submitted to FCC, where it is used as a boundary.

The observer will calculate active power from the phase-to-phase voltage waveform and line current waveform with a minimum time resolution of 1 sample/sec.

4.7.2 The cluster's technical requirements

The requirements are presented in Table 8.

Table 8 - Technical requirements for cluster G (Tie-line power)

Type	Value	Comments
The input signal	Voltage and current waveform	
The output signal	Tie-line power	
Required time resolution (sampling frequency)	1000 Hz	

Type	Value	Comments
Time stamp	No	
Maximum latency allowed (including the communication part)	< 1 sec	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	Mainly HV and MV	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Transmission and distribution, at field.	IED in transmission and distribution.
Accuracy	1 %	

4.8 Cluster H (Cell-level frequency observation)

4.8.1 Description of the cluster

This cluster includes the observable of frequency at cell level which is connected with the UCs FCC, BRC and BSC. In particular, for the UCs of FCC and BRC it is evident that frequency observation is of top priority since the two control schemes deal with frequency stability and regulation. The use of frequency observation in BSC on the other hand is related to the calculation of the imbalance that is then used in the negotiation process. In principle, FCC, BRC and BSC make use of the same frequency observable, yet FCC involves also the droop control of DER which observes frequency locally at the DER's connection. However, this part of the control process has been omitted from the UCs and, therefore, the specific observable is not considered.

In terms of implementation, this observable is most likely located at CTL0. This is based on the minimum technical requirements for the frequency observation at cell level. These requirements specify that a cell frequency can be monitored at a reference bus, by means of a PMU or a Transducer. The output signal is communicated to the cell controllers function for further processing and control actions. The algorithm that have been considered as possible implementation schemes are the Phase-Locked Loop (PLL), the Dual Second-Order Generalised Integrator Frequency-Locked -Loop (DSOGI-FLL) and Finite Impulse Response or Infinite Impulse Response filters. In all cases the input signal is the instantaneous voltage waveform.

From a technical implementation viewpoint, the minimum sampling time requirement for the input signal is 1ms, thus leading to 20 samples per voltage waveform period. On the other hand, the minimum requirement for output signal's resolution is 1 s or less. Also, the required precision is 0.01 Hz whereas, in order to avoid oscillations in the control process the latencies of the communication signals should not exceed 1 ms.

4.8.2 The cluster's technical requirements

The technical requirements are presented in Table 9.

Table 9 - Technical requirements for cluster H (Cell-level frequency observation)

Type	Value	Comments
The input signal	Voltage waveform	
The output signal	Frequency	
Required time resolution (sampling frequency)	1000 Hz	
Time stamp	No	
Maximum latency allowed (including the communication part)	<1 ms	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	Mainly MV and LV	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Process, Field/Voltage transformer, PMU or transducer, IED, SCADA	
Accuracy	0.01 Hz	

4.8.3 Possible implementation

In terms of implementation, this observable is most likely located at CTL0. This is based on the minimum technical requirements for the frequency observation at cell level. These requirements specify that a cell frequency can be monitored at a reference bus, by means of a PMU or a Transducer. The output signal is communicated to the cell controllers' function for further processing and control actions. The algorithm that have been considered as possible implementation schemes are the Phase-Locked Loop (PLL), the Dual Second-Order Generalised Integrator Frequency-Locked -Loop (DSOGI-FLL) and Finite Impulse Response or Infinite Impulse Response filters. In all cases the input signal is the instantaneous voltage waveform.

From a technical implementation viewpoint, the minimum sampling time requirement for the input signal is 1ms, thus leading to 20 samples per voltage waveform period. On the other hand, the minimum requirement for output signal's resolution is 1 s or less. Also, the required precision is 0.01 Hz whereas, in order to avoid oscillations in the control process the latencies of the communication signals should not exceed 1 ms.

4.9 Cluster I (Voltage)

4.9.1 Description of the cluster

The cluster consists of three-phase node voltage measurements used for voltage control, both PVC and PPVC. The measurements are performed at device level (CTL-0) and with system response (CTS-0). In PVC, the observer is used to minimise transient voltage deviations, in PPVC, the observer is used to check if each cell node is in the regulatory safe band. If the voltage is outside the safe band, the PPVC Set-point Provider function will be executed.

The observer will calculate the moving average RMS value of each phase-to-phase voltage waveform and output the average of these.

4.9.2 The cluster's technical requirements

The technical requirements are presented in Table 10.

Table 10 - Technical requirements for cluster I (Voltage at device level)

Type	Value	Comments
The input signal	Voltage waveform	
The output signal	RMS voltage (Three-phase)	
Required time resolution (sampling frequency)	1 Hz-5 kHz	1000 - 5000 Hz for PVC 1 Hz for PPVC
Time stamp	No	
Maximum latency allowed (including the communication part)	1 ms	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	MV and LV	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Generation, transmission, distribution and DER, at Field.	IED in generation, PMU or IED in transmission and distribution and DER controller in the DER-column
Accuracy	0.5 %	

4.9.3 Possible implementation

Voltage measurement is typically performed by energy resources because these resources are in the same time used for voltage control or require voltage measurement for internal control. System flexibility resources, like OLTCs or FACTS, also carry out voltage measurement as they are often used for voltage control.

In other locations, node voltages can for instance be measured by AMIs or PMUs. In the LV grid, it will be naturally to use the information from the AMI systems. These systems will measure, collect and analyse energy usage and voltage. For MW and HV grids, PMUs could be used for measuring.

4.10 Cluster J (Imbalance estimation)

4.10.1 Description of the cluster

The specific cluster involves one observable used by the BSC use case in order to estimate the amount of imbalance in cell. In order to do this, BSC uses the output signal of the Imbalance Correction function in order to estimate when the imbalance has been corrected and how much the amount of correction was. The estimation of the former aspect is based on the monitoring of the rate-of-change of the Imbalance Correction's output. This way, once the output of the BRC controller stabilises the Cell Setpoint Adjusting function can determine the latter aspect (amount of correction) by measuring the output signal of the Imbalance Correction. This measurement provides a good approximation of the amount of imbalance that the BSC control has to manage.

4.10.2 The cluster's technical requirements

The technical requirements are presented in Table 11.

Table 11 - Technical requirements for cluster J (Imbalance estimation)

Type	Value	Comments
The input signal	Tie-lines active power and frequency	
The output signal	Amount of Imbalance (power)	
Required time resolution (sampling frequency)	1000 Hz	
Time stamp	No	
Maximum latency allowed (including the communication part)	<1 s	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	All voltage levels apply	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Process, Field/Voltage transformer, PMU or transducer, IED, SCADA	
Accuracy	1 W	

4.10.3 Possible implementation

Since the specific cluster makes use of the BRC output, the implementation for the BRC control can be used in this cluster. In principle, both the IC and CSA functions are on the same SCADA system of the cell control room and they refer to CTL-2. Regarding the input signals, both the tie-line powers and frequency can be measured using infrastructure described in the previous sections. Therefore, the frequency measurement at cell level can be monitored at a reference bus, by means of a PMU or a Transducer. The output signal is communicated to the cell controllers function for further processing and control actions. Also, the tie-line power can be observed by means of power transducers at the cell's tie-lines. Both signals are processed and combined together in order to be fed as input to the BRC functions which, in turn, correct the imbalance whenever this happens.

4.11 Cluster K (Grid impedance estimation)

4.11.1 Description of the cluster

The cluster entails one observable used only in one function, the grid impedance estimation function. This function provides necessary data for the PVC regulator if it is configured to use not only reactive power for the purpose of voltage control, but also active power. Based on the measurements of voltage at the bus to which the resource is connected and also the current fed by the resource to the grid, the algorithm tracks grid impedance changes. In case it detects a large mismatch, it forces a small step (0.01 - 0.05 pu) in current for a short period of time (0.1 - 1 s) in order to measure the resulting change in grid voltage. The measurements are then used by the algorithm by means of filtering and applying formulas for calculating the observables (resistance and reactance of the impedance).

4.11.2 The cluster's technical requirements

The technical requirements are presented in Table 12.

Table 12 - Technical requirements for cluster K (Grid impedance estimation)

Type	Value	Comments
The input signal	Voltage and current waveform	
The output signal	R and X values	The output signal are the values calculated by estimation algorithm
Required time resolution (sampling frequency)	1 kHz	
Time stamp	No	
Maximum latency allowed (including the communication part)	500 ms	
Reference location according to the network's voltage level (HV; MV; LV or more specific) – distinguish between transmission and distribution	LV and MV	
Reference location to the network's Control Topology Level (SGAM's zones) / specific components	Generation and DER	
Accuracy	1%	

4.11.3 Possible implementation

This observable can be implemented in principle on virtually any controllable energy resource such as RES or conventional generators. The main requirements are access to voltage and current measurements of the resource and an ability to change its power or current reference by a supplementary signal. Thus the best results can be achieved if it is implemented on a highly controllable resource like converter-fed generators used in RES.

5 Mapping of Observables onto Smart Grid Reference Architecture (SGAM)

The main intention of the present section is to evaluate and make a proposal for possible physical implementation of components to obtain the identified observables, within a Web-of-Cells architecture. This will provide, for each of the Use Cases for the Web-of-Cells controls, operative input data sufficient for generation of observables, and will also be useful to better understand WoC functional aspects, regarding both how observables are handled in UCs and how UC control functions work.

5.1 Background and the approach

During the ELECTRA project mapping of Uses Cases to various layers of SGAM has been done several times. There is a certain variation among these mappings, which reflects the ongoing evolution of the WoC concept and the corresponding Use Cases as well as the scope and purpose of the mapping.

For the present deliverable, the most relevant mapping was done in activity “Standards Applicable to Smart Grid Interfaces” for definition of the existing standards and gap analysis for the proposed voltage and frequency controls. The mapping was done to several layers in SGAM and presented in [3]. Following the objectives of this document, this mapping was primarily concerned with the information and communication layers. In some cases the mapping included several variants due to differences on the communication side; these however do not have implications for the observables as such. This mapping clearly served the purpose of the task and led to results with regard to clarification of the standard-related aspects.

The present task intends to come up with more concrete and reasonable proposal for a real-life implementation of the UC observables. Therefore, it does not focus on the standards from the above mentioned activity. Rather, in the mapping procedure care is now taken of the component and function layers.

Besides, with respect to the mentioned work another approach has been chosen i.e. instead of connecting each observable to a specific component as for example a PMU, each defined cluster of observables has been mapped to a generic measuring device, which complies with a set of technical requirements. Physical requirements for the observables define more specifically quantifiable physical attributes, which are necessary in order to meet the observability needs. Specific categories for the requirements were initially proposed in the previous activity (see [1]) and have been modified during the project. These categories are the following:

- **The output signal**: The physical nature of the signal, generated by the metering device i.e. current, voltage etc.
- **Required time resolution (sampling frequency)**: Number of samples obtained in one second. This requirement can be described as a minimum value.
- **Time stamp**: For many observables it is important to know with ample detail when they were observed.
- **Maximum latency allowed:** For data or data transfer from source to destination. This requirement can be described as a maximum allowable period of time. Several observability needs, in fact, have to be met within a certain time period and may become worthless if not.
- **Reference location according to the network's voltage level** (HV; MV; LV or more specific) – distinguish between transmission and distribution: The reference location, where the observability has to be met. It does not necessarily mean that the actual measurements have

to be done in the same place. The observability can be derived based on measurements in other places or/and by other calculations. This applies to local observables and may be irrelevant in case of global observables as for example frequency.

- **Reference location to the network's Control Topology Level** (SGAM zones) / specific components
- **Accuracy:** The closeness of measurements to the exact or true values. Inaccuracies of measuring the "true" variable values due to the fallibility of the measuring instrument, data entry errors or respondents error are defined by measurement error value [9].

For implementation, a first suggestion for measuring components, meeting the least technical requirements, has been made here (see Section 4). The next step will be to introduce these devices, or more generic ones, into the component level of SGAM, also to see how the WoC concept can be implemented in a most cost-efficient way.

In this section, therefore a component-layer SGAM mapping is reported for each UC, based on the UC description and complementing the previous SGAM mappings about functional, information and communication layers. Such a mapping will be useful to develop a more general component-layer mapping based on the measuring device technical requirements derived from the observable clustering process.

5.2 Inertia Response Power Control (IRPC)

The overall rationale of IRPC functions regarding CTL-2 (Cell Operation) is described in [6] and is also including CTL-1 and CTL-0. It can be mapped into SGAM function layer as shown in Figure 6.

As previously mentioned (see Section 2.3) the cell-level functions determine the synthetic inertia setpoint for flexible resources within a cell every CTS-3 time step in order to ensure the required level of overall cell inertia. In this way, the flexible resources deliver the power variations corresponding to the inertia value set in their local controllers: This is done in real time (CTS-0) and at CTL-1 and CTL-0 level, according to the ROCOF measured locally. One has to remark that, in Figure 6, the cell-level functions are depicted in the market zone: This is an example, but, according to the specific implementation choice, they may also be referred to the enterprise or operation zone.

All the mentioned IRPC functions operate both in normal conditions and in case of incidents, such as a significant loss of load or generation cause a relatively large and fast active power imbalance.

A possible SGAM mapping in terms of component layer is shown in Figure 7. Again, one can remark that, depending on implementation choices, the lower-level devices, from the front end below, may be placed in the customer premises zone, instead of the DER zone [2].

Another example of SGAM mapping, in terms of control functions, components and signal exchanges and at different CTLs, is highlighted in [3] and summarized in Figure 8. One can see in the figure how the cell operators in a synchronous area interact in order to define the whole synchronous area synthetic inertia requirement. This is in particular important when the mentioned incidents occur and a correction of the normal conditions synthetic inertia value is necessary. Such correction depends on a detected overall power imbalance. The correction of the normal conditions synthetic inertia value is translated into a correction of the cell synthetic inertia setpoints, and in turn, into a correction of the synthetic inertia setpoints for the flexible resources inside the cell (s). The power imbalance may in particular be affecting only one or some cells. Therefore, it may require a correction of the cell synthetic inertia setpoint for the involved cell(s) only, and in turn, a correction of the synthetic inertia setpoints for the flexible resources inside the involved cell(s) only.

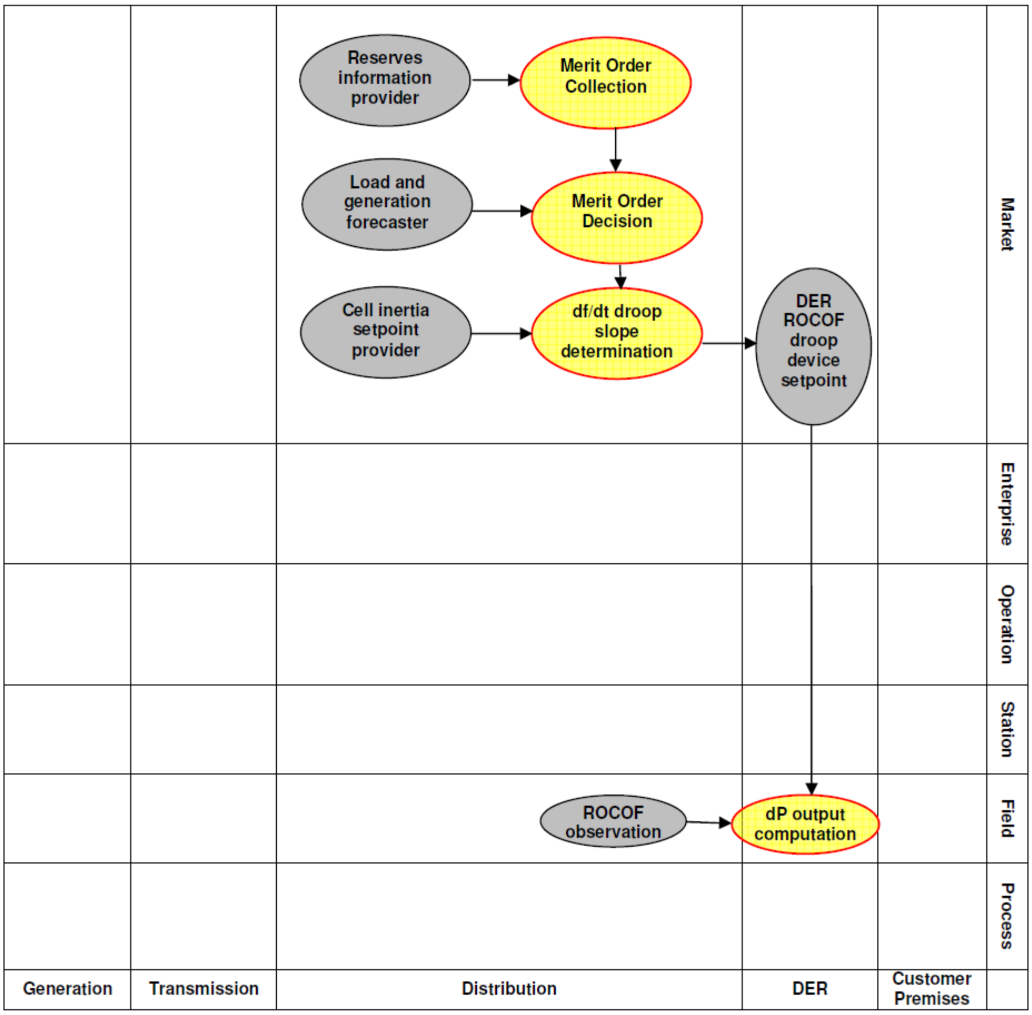

Figure 6 - Mapping the IRPC functions into SGAM Function Layer

For completeness, one can remark, as already hinted at, that the cell operators' interaction may also define the synchronous area synthetic inertia requirement for normal operating conditions. This definition may be done either at CTS-3 time scale, or at agreed longer time intervals, such as on a yearly basis. This is a similar to what is done for frequency containment today when the TSOs decide the network power frequency characteristic participation factor in each control area or control block.

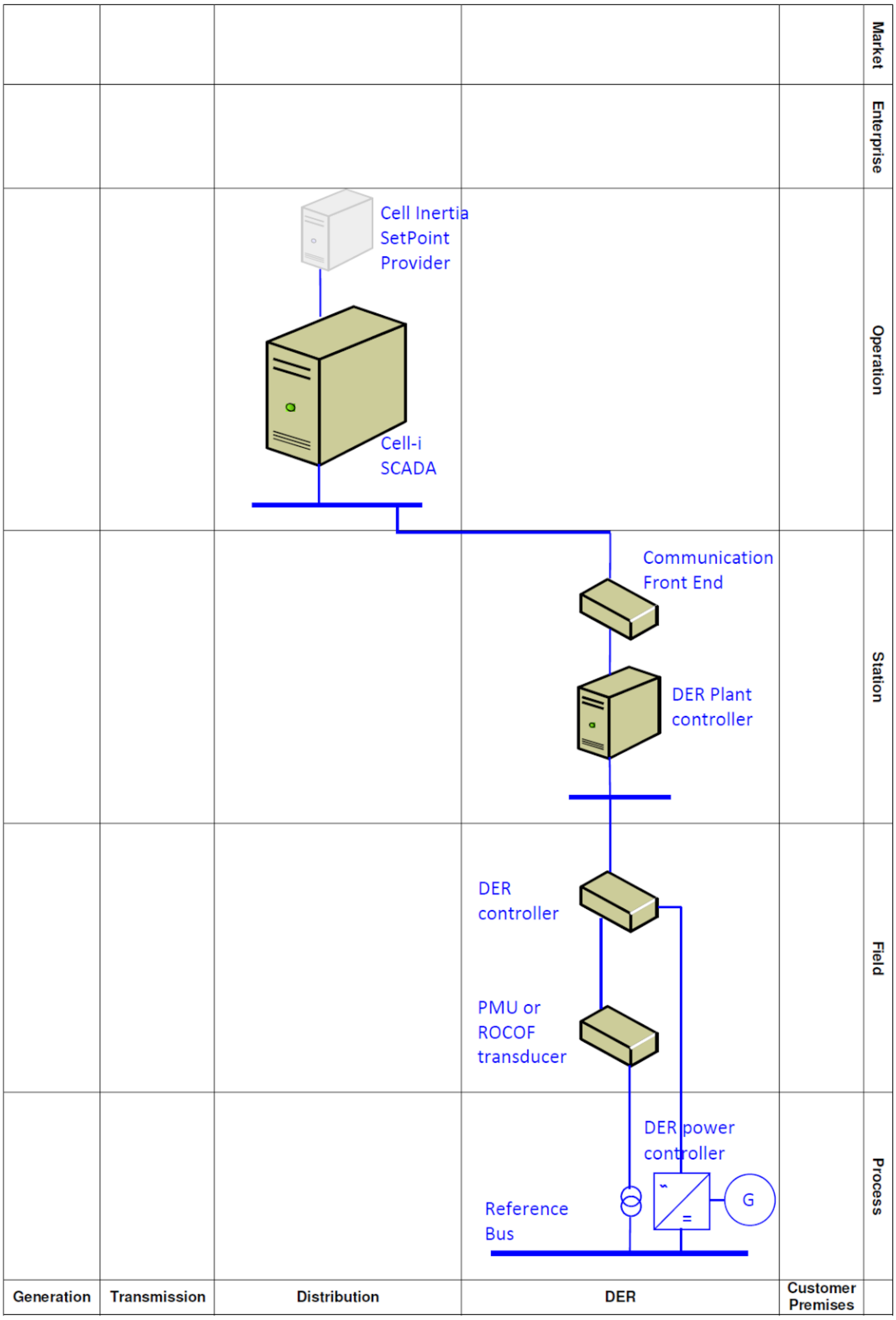

Figure 7 - Mapping of the IRPC into the SGAM Components Layer.

Finally, from a technical point of view, one can notice that a required amount of synthetic inertia, or similarly a synthetic inertia setpoint, can be expressed as an equivalent moment of inertia J or an equivalent inertia constant H.

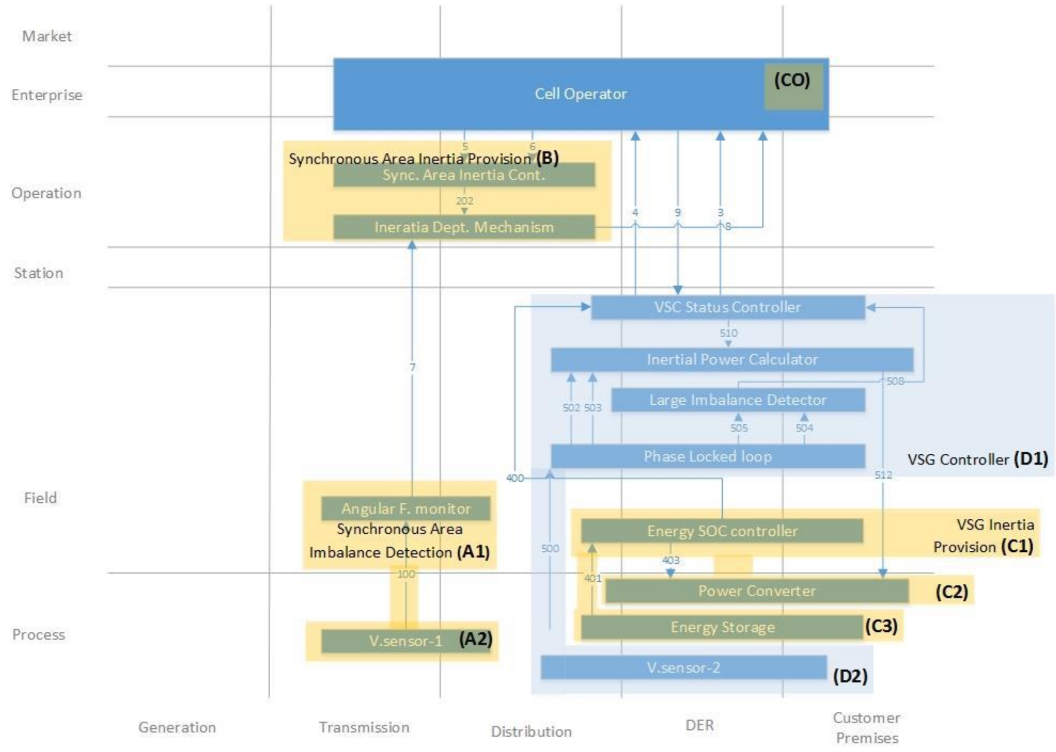

Figure 8 - Detailed SGAM mapping with functions, possible components and information exchanges, for IRPC. Source: Figure 27 in [3]

5.3 Frequency Containment Control (FCC)

A mapping of the FCC use case to SGAM is presented in Section 3.4.1 in [3]. This analysis contains both the function layer, the information layer, the communication layer and the component layer. However, since this mapping had different goals, mostly concentrating on communication standards, a new mapping of the function layer is derived and presented in this chapter.

The implementation of the function layer is presented in Figure 9. The function layer drawn based on the use case description given in [6]. The functions and their placement in the SGAM diagram are explained in the following:

- Functions placed under *Market* and *DER* in the SGAM diagram. These are placed here because the Merit Order is decided by the marked. They are all performed by the cell controller.
    - *Merit Order Collection*: This function receives reserves flexibilities (or availabilities) from the *Reserves Information provider function*, and collates them in a list ranked by cost. The resulted list is submitted to the *Merit Order Decision* function for final improvements.
    - *Merit Order Decision*: This function calculates the final Merit Order list by taking into consideration the operating constraints of the grid on which these reserves are to be deployed. The function receives the initial input by the *Merit Order Collection function* and delivers the final Merit Order list to the *Frequency Droop Parameter determination function.*
    - *Reserves Information Provider*: This function provides the available power capacity that is needed for the compilation of the Merit Order List by the *Merit Order Collection function*.

  - *Load & Generator Forecaster*: This function provides the scheduled production and consumption of all generators and loads in order to be used by *the Merit Order Decision function* for the calculation of the optimal reserves.
- Functions placed under *Operation* and *Distribution* in the SGAM diagram. These are all performed by the cell controller on an operation level.
  - *Frequency Droop Parameter Determination*: This function receives the cell's CPFC from the *Cell CPFC Setpoint Provider* function for the next timestep. Based on the final Merit Order list it receives from the *Merit Decision Order function,* it determines the droop slopes and deadbands for each *Frequency Droop Device* in such a manner that the aggregated droop slope is equal to the CPFC.
  - *Adaptive CPFC Determination*: This function calculates the instantaneous droop scaling factor based on the cells' imbalance state it receives from the *(BRC) Imbalance Determination function* and the frequency it receives from the *Frequency Observation function*. This scaling factor is sent to all *Frequency Droop devices.*
  - *Cell CPFC Setpoint Provider*: This function provides the cell's CPFC setpoint to the *Frequency Droop Parameter Determination function.*
  - *Frequency Observation*: This function calculates and provides frequency measurements to the *Adaptive CPFC Determination function.*
  - *Imbalance Determination (BRC):* This function provides the determined imbalance that was calculated by BRC. The function is performed by the BRC Use Case.
- Function placed under *Field* and *DER* in the SGAM diagram since the function is performed by distributed resources like DER controller.
- *DER – Frequency Droop Device*: This function continuously measures *df* and activates active power in accordance with the droop settings it received from the *Frequency Droop Parameter Determination function* and the scaling factor it received from the *Adaptive CPFC Determination function.*

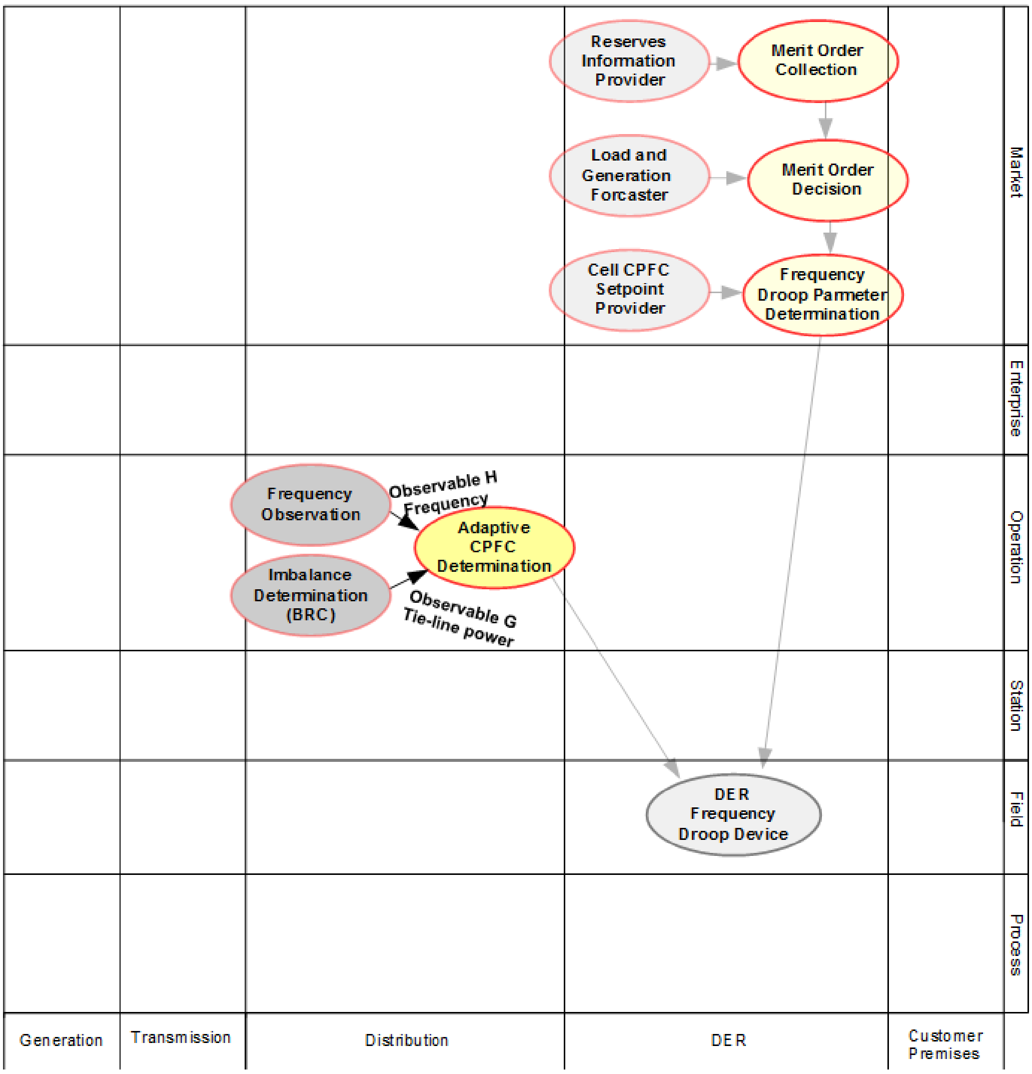

Figure 9 - Mapping of the FCC functions on the SGAM Function Layer

Different implementation options of the components in the component layer will be possible. An example of implementation of the component layer is shown in Figure 10, based on reasonable assumptions derived from relevant standards and available components. In this case, the FCC controls the active power of power converters in DERs. The frequency measurements is performed by embedded processors with PLL, PMUs or frequency transducers in the DER-transformer. The components in the component layer is explained below:

- Embedded processor with PLL: The PLL (Phase-Locked Loop) tracks the frequency based on the voltage and/or current waveform
- PMU: The PMU (Phasor Measurement Unit) measures voltage, current, active power, reactive power and frequency with time stamp.
- DER-controller: Controls the active and reactive power output of the power converter to a received set point.
- Power converter: Converts the power output of the DER to AC voltage. The frequency, voltage and active and reactive power can be controlled.
- DER Plant Controller
- Communication front End
- DER Energy Management System (EMS)/technical Virtual Power Plant (tVPP)/Aggregator: An ICT system which represent the aggregators' underlying function.

- SCADA/Cell System Operator (CSO): Calculates and sends set-points to DER-controllers or Aggregated DER Management Systems.

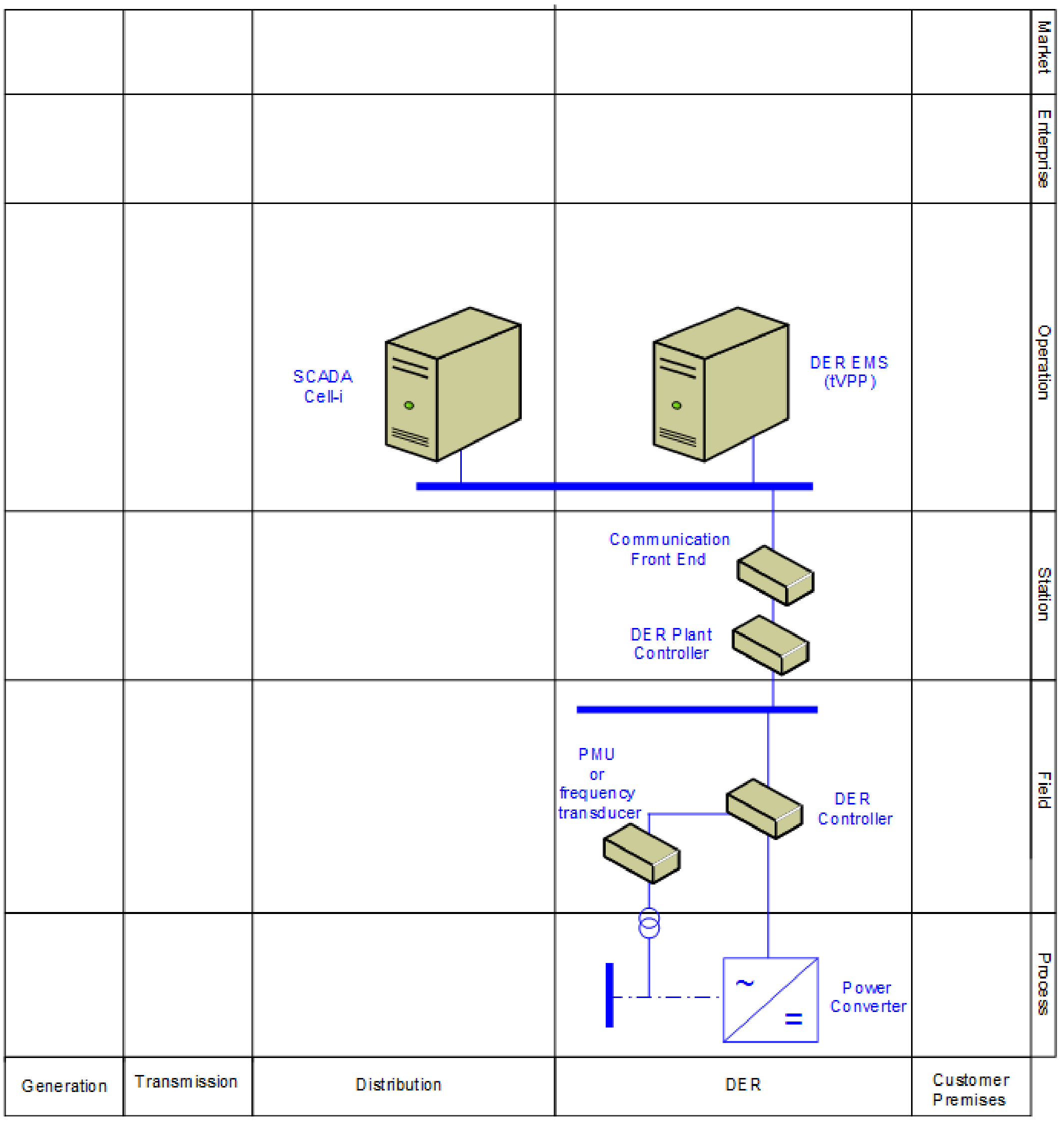

Figure 10 - SGAM Component Layer for FCC - assignment of components to SGAM coordinates at the possible SGAM Component Layer.

5.4 Balance Restoration Control (BRC)

A mapping of two different versions of the BRC use case to SGAM is presented in Section 3.4.1 in [3]. This analysis contains both the function layer, the information layer, the communication layer and the component layer. Based on the work in [6] and [3], a new mapping with focus on the observables is derived and presented in this chapter. The implementation of the function layer is presented in Figure 11. The function layer drawn based on the use case description given in [6]. The functions and their placement in the SGAM diagram are explained in the following:

- Functions placed under *Market* and *DER* in the SGAM diagram. These are placed here because the Merit Order is decided by the marked. They are all performed by the cell controller.
    - *Merit Order Collection*: This function receives reserves flexibilities (or availabilities) from the *Reserves Information provider* function, and collates them in a list ranked by cost. The resulted list is submitted to the *Merit Order Decision* function for final improvements.

  - *Merit Order Decision*: This function calculates the final Merit Order list by taking into consideration the operating constraints of the grid on which these reserves are to be deployed. The function receives the initial input by the *Merit Order Collection* function and delivers the final Merit Order list to the *Imbalance Correction* function.
  - *Reserves Information provider*: This function provides the available power capacity that is needed for the compilation of the Merit Order List by the *Merit Order Collection* function.
  - *Load & Generator forecaster*: The function provides the scheduled production and consumption of all generators and loads in order to be used by the *Merit Order Decision* function for the calculation of the optimal reserves.
- Functions placed under *Operation* and *Distribution* in the SGAM diagram. These are all performed by the cell controller on an operation level.
  - *Imbalance Determination*: This cell central function collects and aggregates the tie-line observed active power flows received from the *Tie-line Active Powerflow Observation* function and compares this against the cell setpoint received from the *Tie-line Active Powerflow Setpoint Provider* function to determine a cell balance error signal that is provided to the *Imbalance Correction* function.
  - *Imbalance Correction*: This cell-central function receives the cell balance error signal from the *Imbalance Determination* function, and uses the final Merit Order list that it received from the *Merit Order Decision* function to send active power dispatch commands to *Controllable P devices.*
  - *Tie-Line Active Power Setpoint provider*: The function provides the individual tie-line power flows for calculating the total cell imbalance.
  - *Tie-line Active Power Observation*: This function calculates and provides active power flow measurements to the *Imbalance Determination* function.
- Function placed under *Field* and *DER* in the SGAM diagram since the function is performed by distributed resources like DER controller.
  - DER – *Controllable P device*: The function is continuously receiving and responding to active power activation and deactivation commands from the *Imbalance Correction* function.

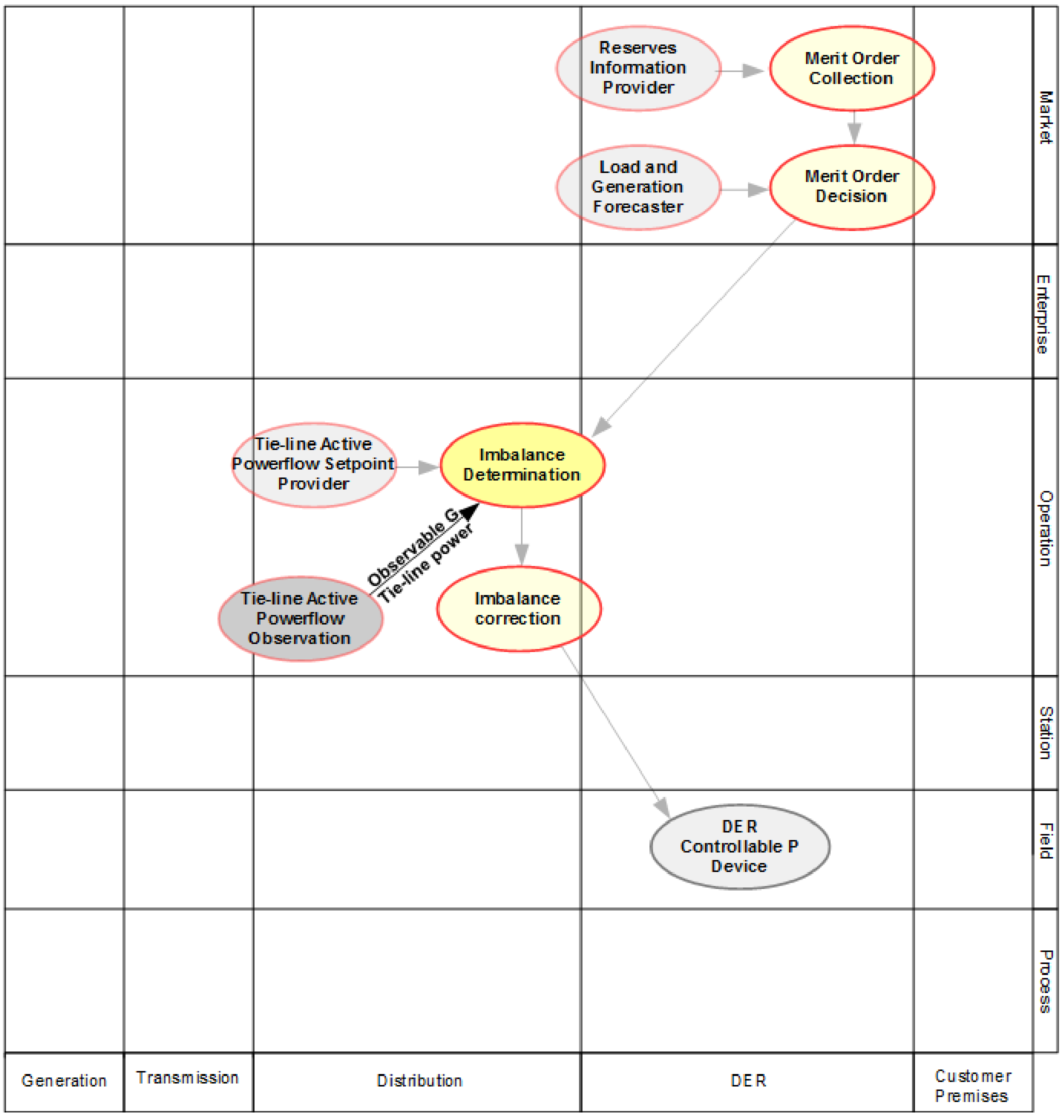

Figure 11 - Mapping of the BRC1.1 and 1.2 functions on the SGAM Function Layer

For the present task the difference between the two variants of the BRC use case is not essentials, thus only the mapping in the component layer of BRC 1.1 and 1.2 is depicted in Figure 12, where RTUs and IEDs are applied for monitoring the cell's power flows. The main components in the component layer is described in the following:

- IED (Intelligent Electronic Device): Receive data from sensors like voltage and current transformers and able to communicate information like voltage, current and frequency.
- RTU (Remote Terminal Unit): Interface between the measurement units and CSO or SCADA.
- DER-controller: Controls the active and reactive power output of the power converter to a received set point.
- DER Plant Controller:
- ER Energy Management System (EMS)/technical Virtual Power Plant (tVPP)/Aggregator: the central entity for controlling a cluster of distributed energy generation installations

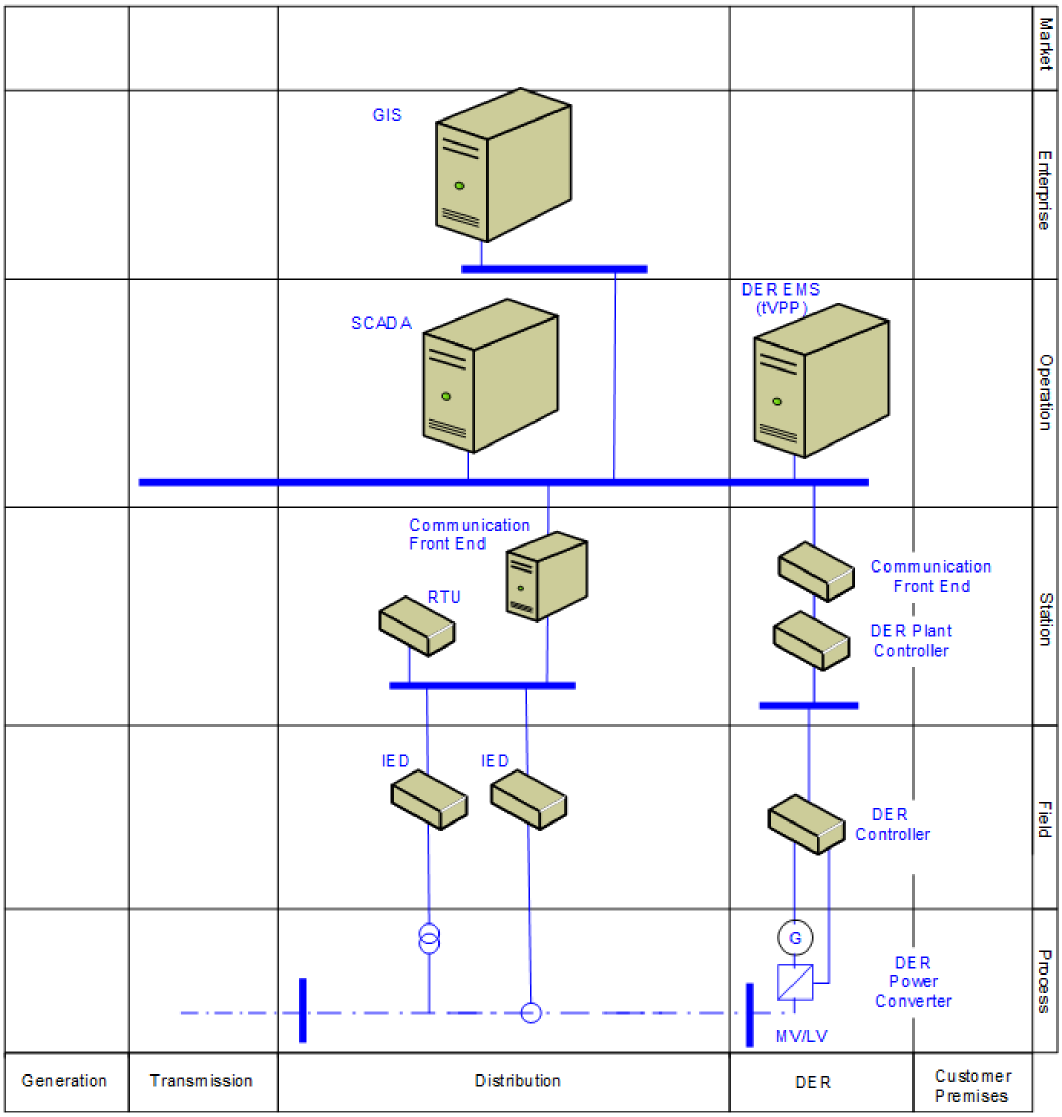

Figure 12 - SGAM Component Layer for BRC - assignment of components to SGAM coordinates at the possible SGAM Component Layer. Source: [3]

5.5 Balance Steering Control (BSC)

Balance Steering Control functions are a set of functions that collaborate with other BRC and FCC functions in order to achieve their goal. The analytical description of these interactions with the other UC functions is provided in [6] and it is beyond the scope of this deliverable. However, for the understanding of the requirements in terms of observables, the complete set of BSC functions and their interactions is mapped on the SGAM function layer, namely in Figure 13 for corrective and in Figure 15 for pre-emptive BSC.

In the diagrams, for the distinction from the generic function set, the functions related to identified observables as well as the observables' signals have been highlighted. More in detail, in the corrective BSC version, the whole set of functions is located in the operation zone of SGAM since all actions and signal exchanges regard CTL2 (Cell Operation). In terms of SGAM domains we have selected the placement of the functions in the Distribution domain although it is possible for the same set of functions to concern a Transmission Grid or a combination of Transmission and Distribution grids. This is due to the fact that by definition, a cell can span to any voltage level and even combine various voltage levels in its domain.

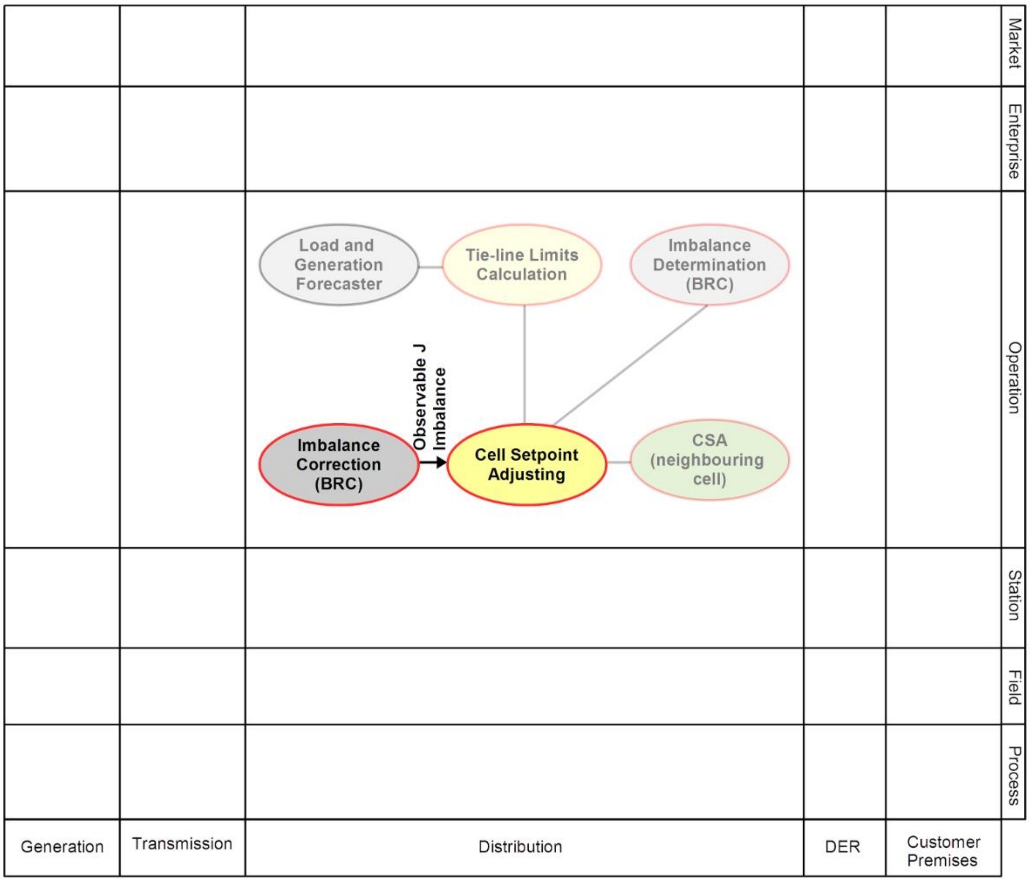

Figure 13 - Mapping of the corrective BSC functions on the SGAM Function Layer

In brief, the meaning of each of the functions illustrated in Figure 13 are the following:

- *Load and generation forecaster*: A function that provides information about the scheduled tie-lines power
- *Imbalance Correction*: The core function of BRC that acts towards restoration of balance. This function's output is also the observable signal for the BSC control. The value of this signal corresponds to the imbalance power in the cell.
- *Imbalance Determination:* This function is also related to BRC and it provides the information of tie-lines deviation. Apparently, this function receives the setpoint adjustments generated by BSC.
- *Tie-line Limits Calculation*: The function that calculates the remaining available capacity for any adjustment required.
- *Cell Setpoint Adjusting:* The function that estimates and negotiates the adjustment of setpoints among cells.

The implementation of the corrective BSC functions in a real-world application should involve components related to the control room of a cell operator. Therefore, as the most representative example we have selected the case in which the SCADA system of a cell is used. As it can be seen in Figure 14, the SCADA system of one cell should communicate with its neighbouring peers which host the CSA for the other cells. However, for the observation of the required imbalance quantity in this UC the only information exchange takes place in the SCADA system of cell-i.

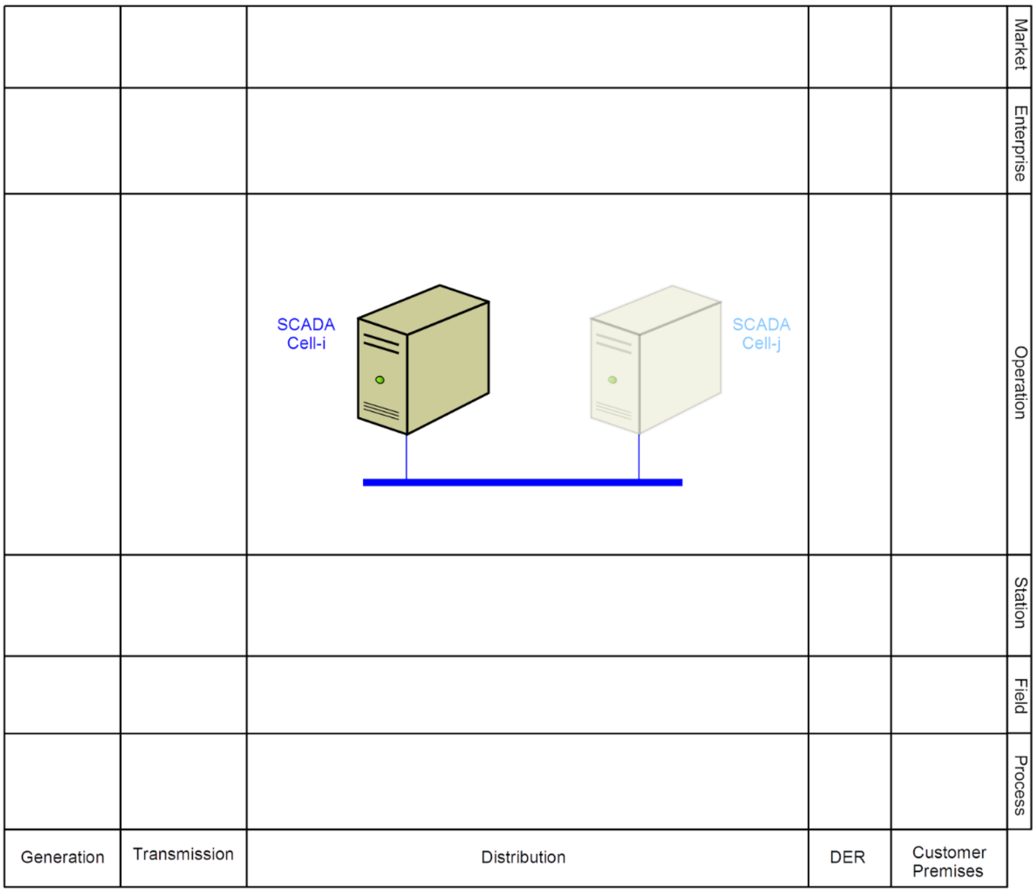

Figure 14 - Mapping of the components that could host the corrective BSC functions on the SGAM Component Layer

Likewise, the pre-emptive BSC version presents a lot of similarities with the corrective one. As it can be seen in Figure 15, the main difference is the use of two functions, the *Cell CFPC Setpoint provider* and the *Frequency Observation* in place of the *Imbalance Correction.* These functions are used in order for BSC to calculate the amount of imbalance. Thus, by observing the frequency and multiplying this value by CPFC the CSA can estimate the amount of imbalance accounted for FCC reserves within the cell. Also, in order to calculate the FCC contribution of other cells through tie-lines CSA uses the second observable which is the tie-line power deviation provided by the *Imbalance Determination.* All the observables and interrelated functions are also highlighted in the specific diagram.

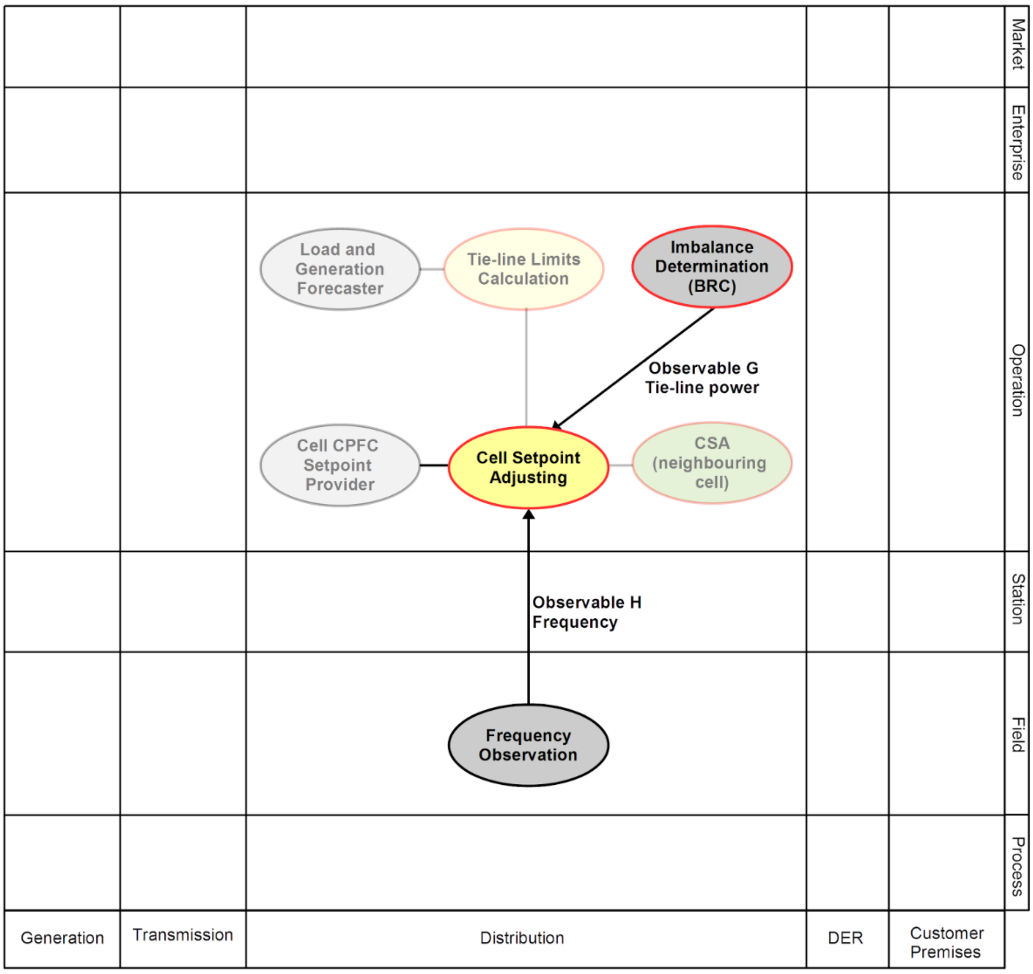

Figure 15 - Mapping of the pre-emptive BSC functions on the SGAM Function Layer

The implementation of this scheme in a real-world application would require the use of a components' set like the one depicted in Figure 16.

In this diagram, the lowest level components that are concerned with frequency and power measurement (e.g. PMU, frequency and power transducers) are all located in the Field zone of SGAM. These components acquire signals by various buses in the process zone. Specifically, for the frequency measurement, and based on a common today's practice a reference bus can be used. This bus is equipped with voltage transformers which step down the grid's voltage to a low level for the transducer's input. The latter unit can convert the input signal to a phase (PMU) or frequency (PLL) value which is then communicated to a local IED. The process of frequency observation, namely the calculation of the final signal required by the control could be considered to end at the IED's level, in the case where only one measurement point is used. Alternatively, the frequency calculation may involve the sampling of multiple buses frequency, which then leads to aggregation and averaging of these values at the SCADA level. In this case, the control level spans from CTL0 to CTL2. However, in our analysis we have assumed only the first case as the most representative one, without, however, excluding any other alternatives.

Similarly, for the tie-lines power the measurement takes place at the tie-lines buses, depicted in Figure 16 by means of both voltage and current transformers. Based on these two signals, proper transducers (e.g. power analysers) calculate the active power of the tie-line. The value is then communicated to the corresponding, local IED. Since the Imbalance Determination function calculates the net imbalance of a cell, the output of this IED is communicated to the SCADA, which aggregates the values of all tie-lines to obtain the imbalance. Therefore, the function essentially spans from CTL0 to CTL2 and for the sake of clarity in our analysis we have assumed that the related function is at CTL2. For the data transmission from the field to the operation zone (namely the cell's SCADA) some intermediate equipment may be used, including RTUs, and Communication Front End devices.

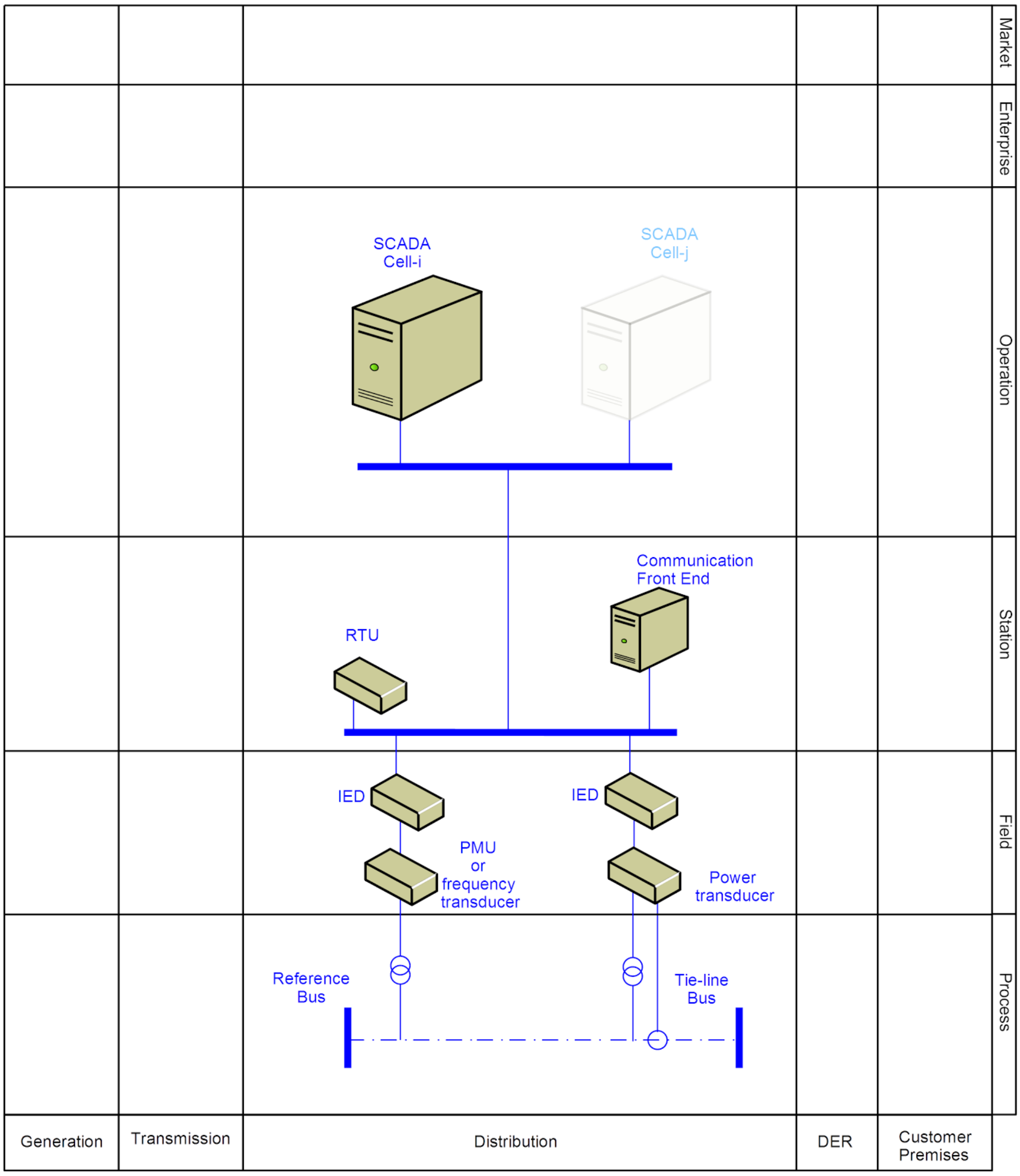

Figure 16 - Mapping of the components that could host the pre-emptive BSC functions on the SGAM Component Layer

5.6 Primary Voltage Control (PVC)

Primary Voltage Control is a voltage control function acting via the controllers of physical devices that are able to perform such action. Besides processing voltage and current measurement data as well as providing command signal for the actuators, PVC communicates with PPVC, whose role is to deliver setpoints and (if necessary) parameters for the PVC. Since PVC is responsible for instantaneous and continuous voltage control, it is located mainly in the field zone of the SGAM function layer. This has been depicted in Figure 17 below.

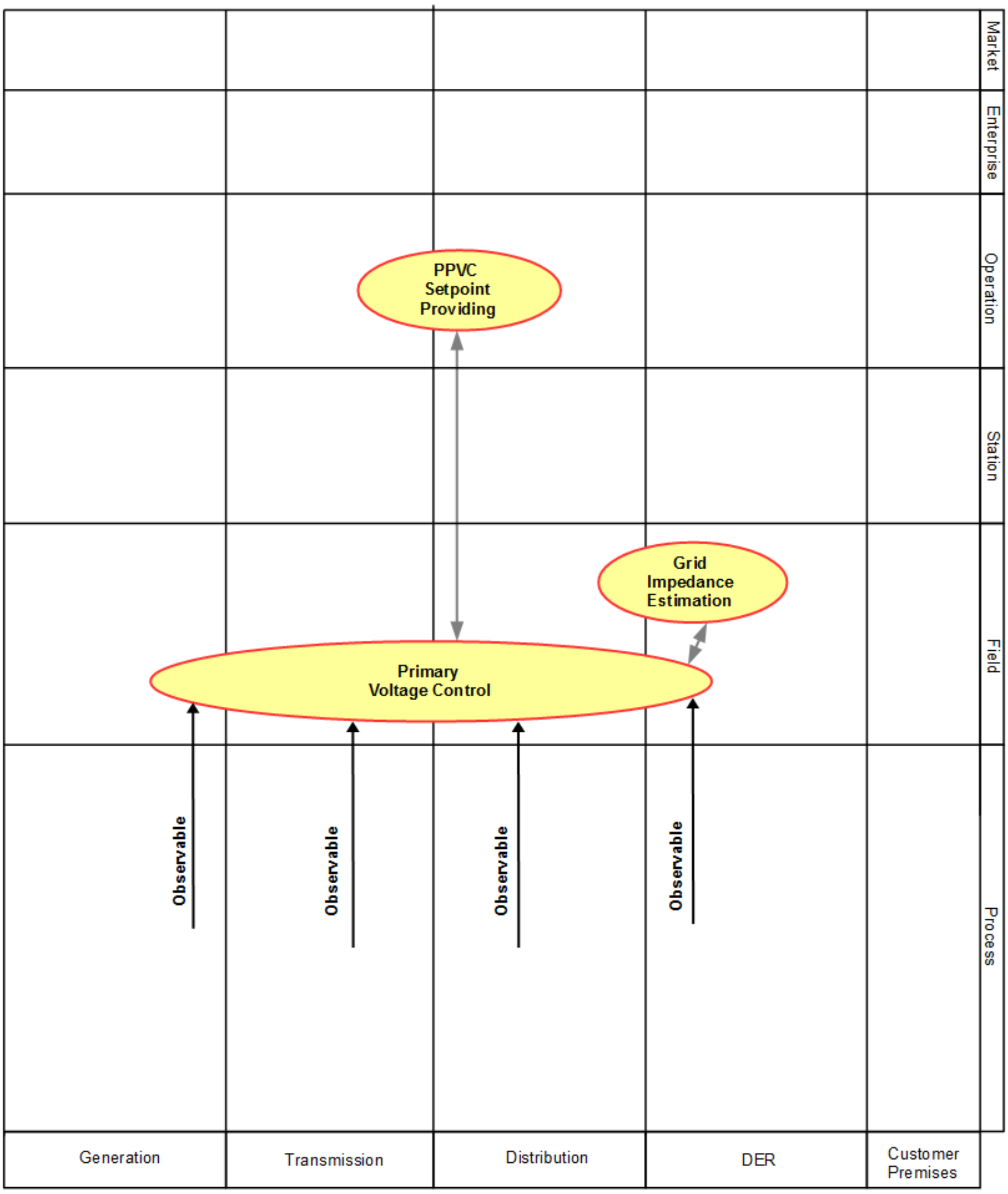

Figure 17 - Mapping of the PVC functions on the SGAM Function Layer

As illustrated in the above figure, PVC extends to those domains, in which voltage regulation can take place. Naturally these are the domains related to generation of electricity (DER and generation domains), but in principle these can also be transmission and distribution domains with Flexible AC Transmission Systems (FACTS) or so-called distribution-FACTS devices as control means. In each case the observable is similar, i.e. instantaneous voltage and current.

A supportive function to PVC is a Grid Impedance Estimation function. Its main goal is to detect and evaluate any impedance changes of the grid and provide the updated information about the grid impedance to the PVC. However rare, this functionality can be important whenever active power takes part in the voltage control process, i.e. in highly resistive low voltage networks, thus it is mainly assigned to distribution and DER domains. On the bidirectional communication path with PVC, this function requires voltage and current measurements as inputs and returns grid impedance amplitude and angle as outputs.

PVC is implemented in such a way that that communication delays and/or any type of distortion in the measurements are minimized. Formally it is achieved by the requirement of CTL-0 (process) and CTS-0 (milliseconds), however in practice it means locating the control device as close to the physical process as possible. For the generation domain, it is equivalent to an automatic voltage regulator (AVR) that performs this function and for DER the PVC is usually integrated within the overall device controller. The necessary components for measurements' acquisition are voltage and current transformers (and/or other sensing equipment) as well as optoelectronic and electronic components whose role is to filter, condition and convert the signals to the digital representation useful for the controllers. In the component mapping of the PVC functions to the SGAM depicted in Figure 18. The VTs and CTs are present in the process zone and the remaining components are schematically incorporated into the respective blocks in the Field zone. Same mapping is applicable to the transmission and distribution domains for FACTS and distribution-FACTS devices (not depicted in the figure for clarity).

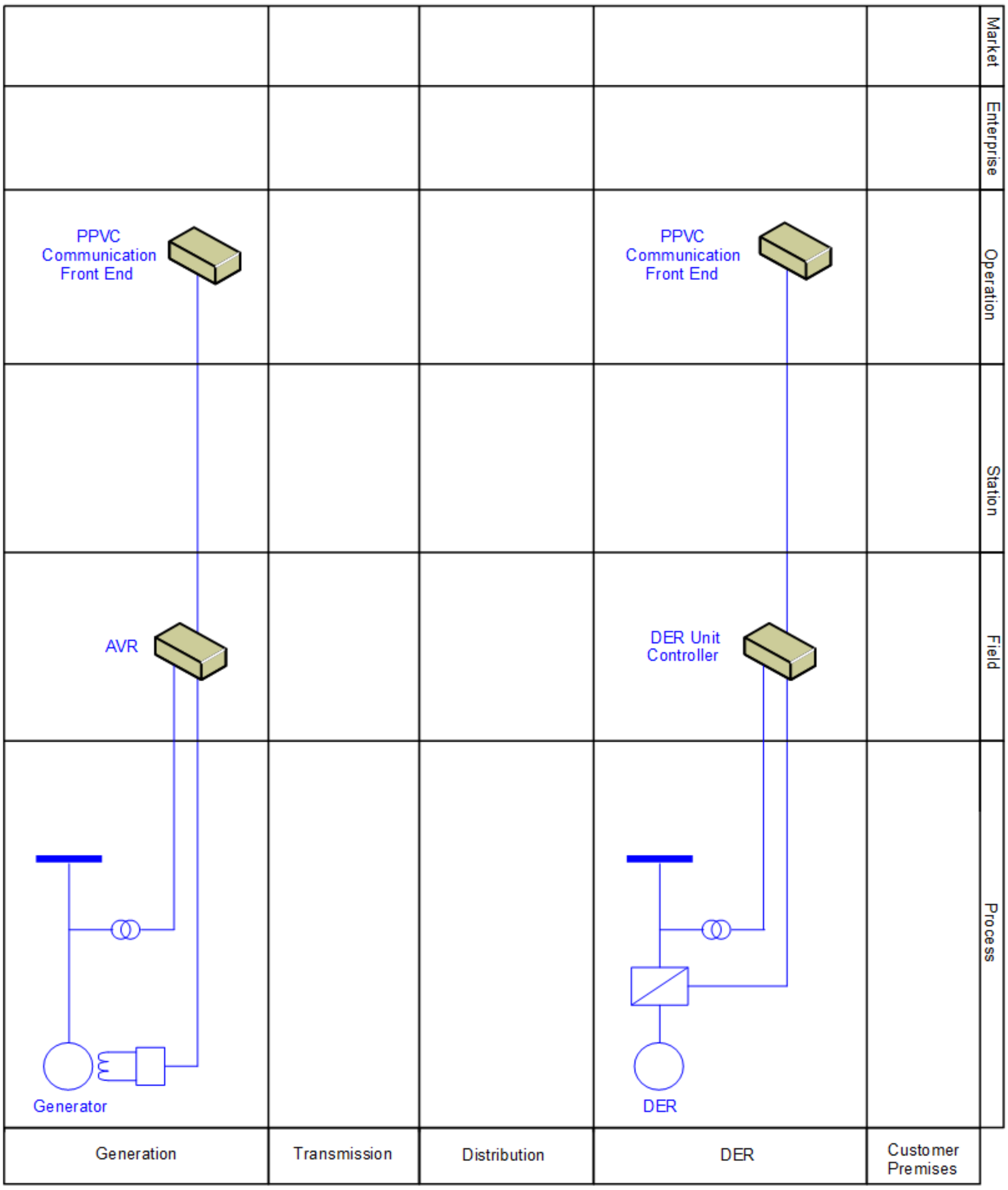

Figure 18 - Mapping of the PVC components on the SGAM Component Layer

5.7 Post-primary Voltage Control (PPVC)

Detailed description of the developed Use Cases is provided in deliverable [6] of the present project and further elaborated in deliverable [10]. For the scope of the present task the most interesting part is combined mapping of PVC and PPVC to SGAM, which was done in the scope of activity "Standards applicable to Smart Grid interfaces" and presented in [3]. This analysis contains both the function layer, the information layer, the communication layer and the component layer. However, since this mapping had different goals, mostly concentrating on communication standards, a new mapping with focus on the observables is derived and presented in this chapter, based on the work in [6] and [3].

The implementation of the function layer is presented in Figure 19. The function layer drawn based on the use case description given in [6]. The functions and their placement in the SGAM diagram are explained in the following:

- Functions placed under *Operation* and *Distribution* in the SGAM diagram. These are all performed by the cell controller on an operation level.
    - *PPVC Controlling*: Upon receipt of a timer trigger or a voltage violation error signal from *Voltage Pilot Nodes*, this function sends a trigger to *the PPVC Setpoint Providing* function to calculate a new voltage control setpoints. Next, it sends the new setpoints that it receives from the *PPVC Setpoint Provider* function to the *PVC (AVR) devices, Controllable Q devices, Capacitor Banks* and *OLTCs.*
    - *PPVC Set-point Providing*: Upon receipt of a trigger from the *PPVC Controlling function*, this function determines new voltage control setpoints for controllable nodes to ensure all node voltages in the cell are within the regulatory safeband, while minimizing power flow losses in the cell. These new setpoints are calculated based on information received from the *Reserves Information Provider* function, the *Load and Generation Forecaster* function, and the *Tie-line Powerflow Setpoint Provider* function. The calculated setpoints are sent back to the *PPVC Controlling* function.
    - *Load & Generator Forecaster*: This function provides the scheduled production and consumption of all generators and loads in order to be used by the OPF in the P*PVC Setpoint Providing function.*
    - *Tie-Line Powerflow Setpoint provider*: This function provides the individual tie-line power flow setpoints to be used by the OPF in the *PPVC Setpoint Providing* function.
    - *Reserves Information Provider*: The function provides the available voltage control resources that is needed for the OPF calculations in the *PPVC Setpoint Providing* function. It can be part of a DER.
- Function placed under *Field* and *DER* in the SGAM diagram since the function is performed by distributed resources like DER controller.
    - *DER – AVR device*: This function measures V and activates reactive power continuously when a value outside the deadband setpoint is observed.
    - *DER – Controllable Q device*: This function activates or deactivates reactive power as requested by the *PPVC Controlling function.*
- Other functions:
    - *Voltage Pilot nodes:* This function compares the locally measure voltage against the regulatory safeband. If there is a violation, a voltage violation error signal is sent to the *PPVC controlling function*. This function is placed in to cover both *generation, transmission, distribution* and *DER* in the SGAM diagram since the voltage can be measured both in the grid and at the production units. It is placed in the *Field* row since the function is performed locally.

- *Capacitor banks*: This function switches the capacitor banks to the position requested by the *PPVC Controlling function.* It is placed under *Process* and *Transmission* (and *Distribution*) in the SGAM diagram since the capacitor banks are controlled directly from the *PPVC Controlling* function.
- *OLTC*: This function switches the transformer tappings to the position requested by the *PPVC Controlling* function. It is placed under *Process* and *Transmission* (and *Distribution*) in the SGAM diagram.

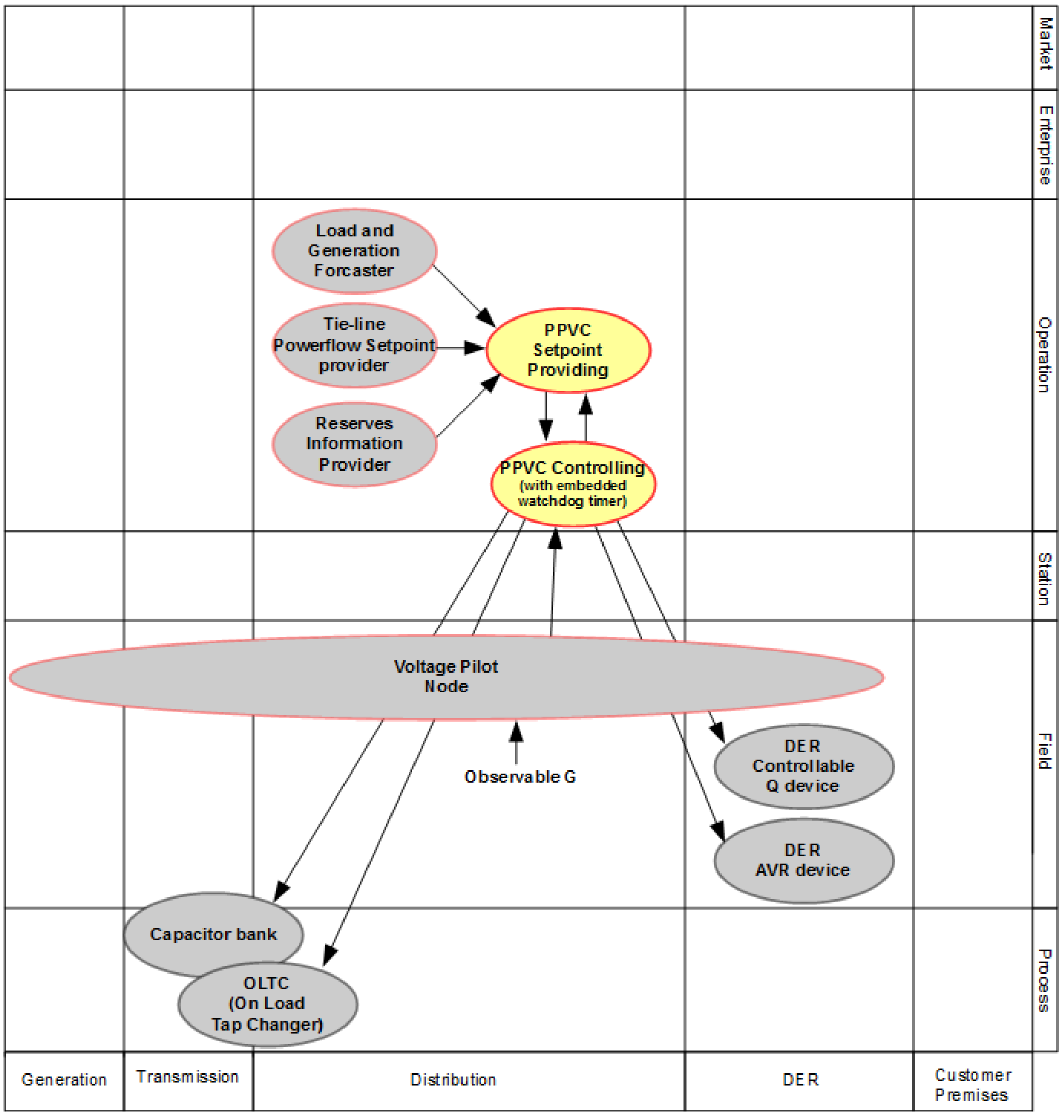

Figure 19 - SGAM Function Layer for PVC and proactive PPVC use cases

The mapping of the SGAM Component Layer for PVC and proactive PPVC use cases is shown in Figure 20. The mapping is similar the mapping presented in [3], however the graphical presentation and the number of component include is changed. Different implementation options of the components in the component layer will be possible. For doing the mapping several reasonable assumptions were made, including presence of SCADA/EMS within a given cell, which receives data from:

- IEDs located in the area of substation busbars of Field zone) or substation RTUs both located in the area of Generation/Transmission/Distribution domains and Station zone.

- Aggregator DER Management System (DER EMS) gathering data from DERs – it is located in the area of DER domain and Operation zone.
- WAMS (Wide Area Measurement Systems) based on PMUs (Phasor Measurement Unit) and PDCs (Phasor Data Concentrators) - PMUs and substation PDCs are located in the area of Generation/Transmission domains and Field/Station zones.
- The central PDC is located close to the CSO SCADA/EMS.
- AMI (Advanced Metering Infrastructure) that is a source of LV network data (e.g. quasi-real-time voltages within the LV distribution network). The AMI data can be obtained directly from AMI Head-End system located in the area of Distribution domain and Operation zone.

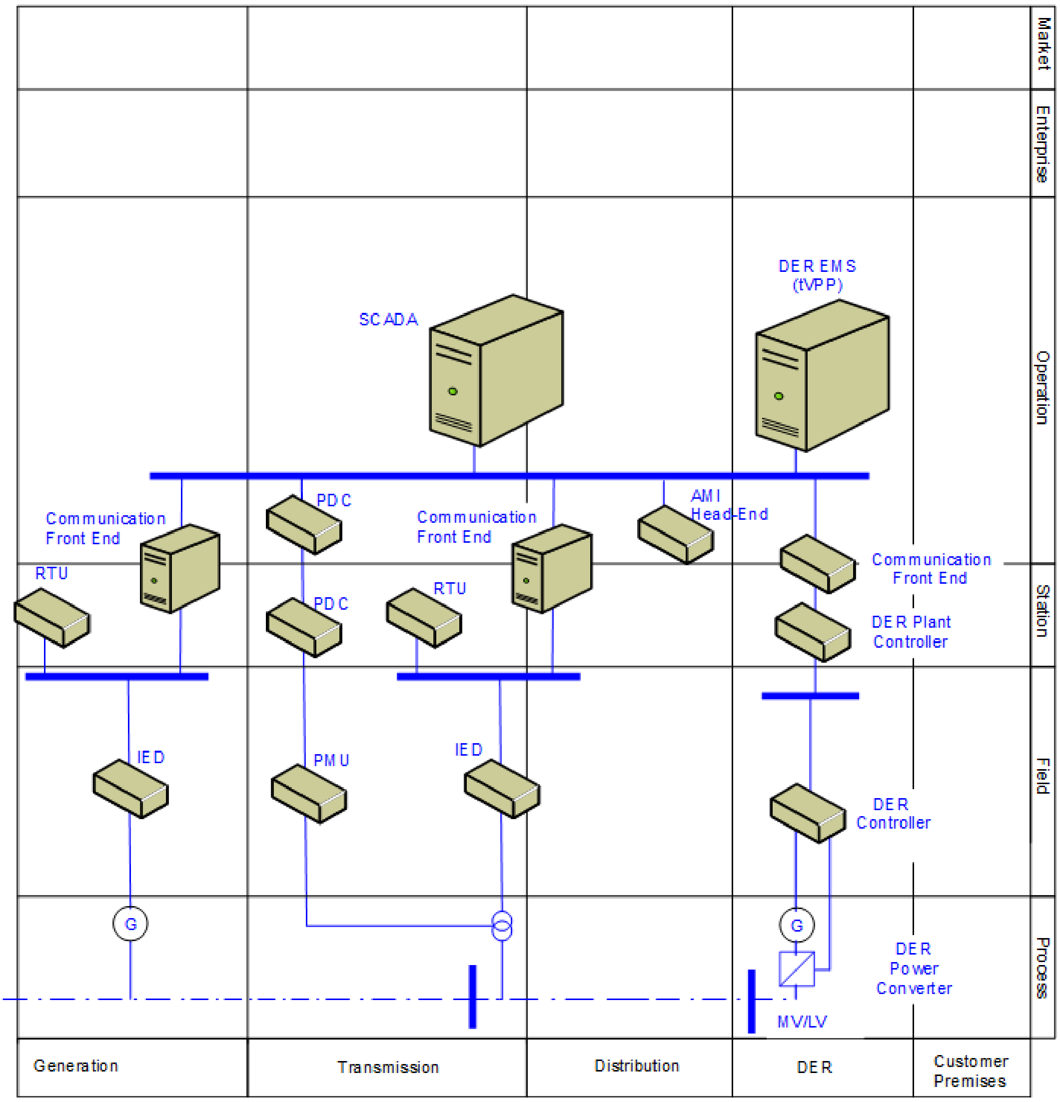

Figure 20- SGAM Component Layer for PVC and proactive PPVC use cases - assignment of components to SGAM coordinates at the possible SGAM Component Layer

5.8 Mapping of all six Use Cases to the SGAM Component Layer

The mapping of all six use cases to the SGAM component layer is presented in Figure 21. This mapping is very similar to the mapping of PVC and PPVC and shows that many components can be used of various use cases. For instance, is the DER Controller, DER Plant Controller and the corresponding Communication Front End used by IRPC, FCC, BRC, PVC and PPVC.

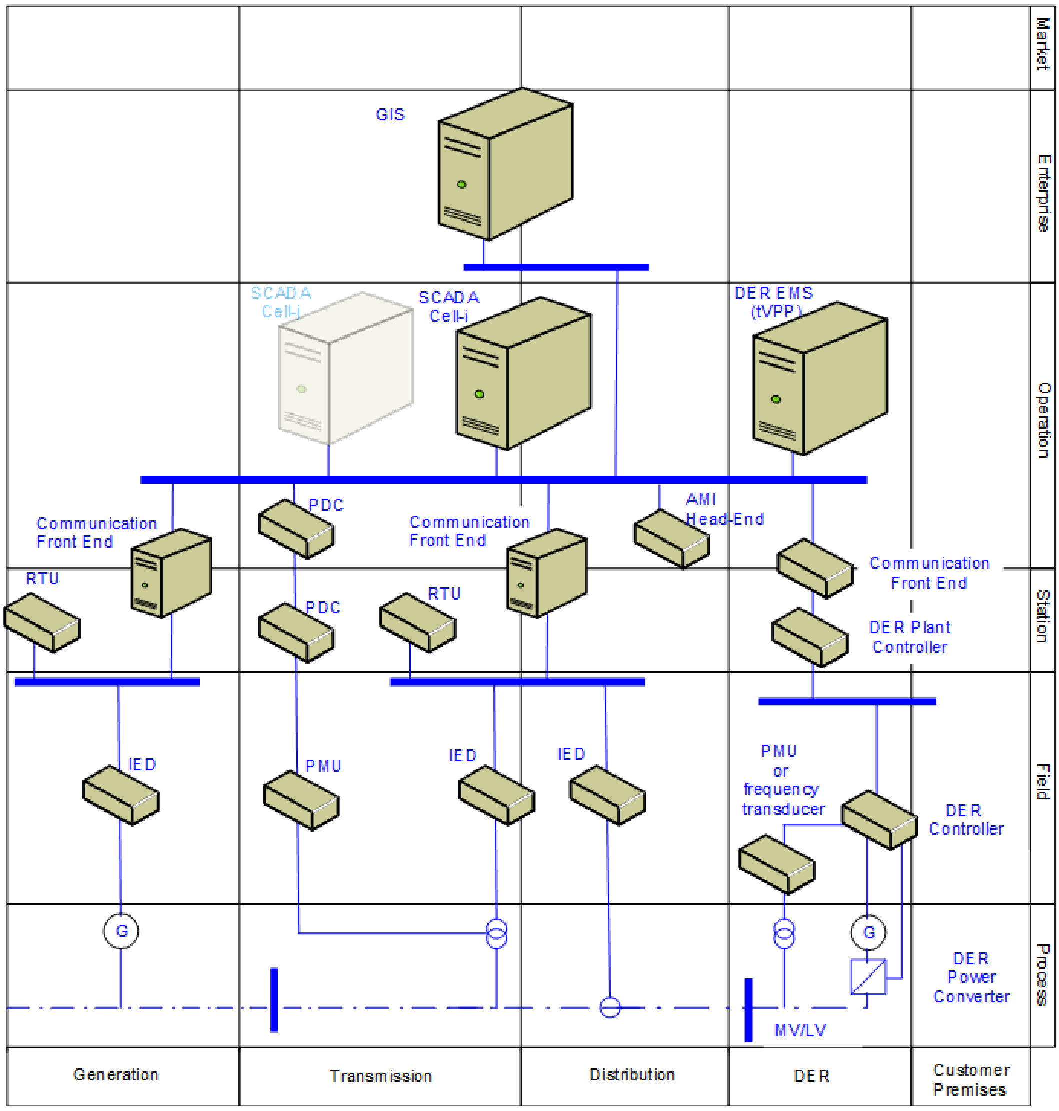

Figure 21 - SGAM Component Layer for IRPC, FCC, BRC, BSC, PVC and PPVC use cases - assignment of components to SGAM coordinates at the possible SGAM Component Layer.

Table 13 summarizes the components and their use in the use cases.

Table 13 - Components used in IRPC, FCC, BRC, BSC, PVC and PPVC use cases

	IRPC	FCC	BRC	BSC	PVC	PPVC
GIS			X			
SCADA - Cell i	X	X	X	X		X
SCADA - Cell j				X		
DER EMS (tVPP)		X	X			X
Generation						
Communication Front End				X*	X	X
RTU				X*		X
IED					X	X

	IRPC	FCC	BRC	BSC	PVC	PPVC
Transmission/Distribution						
Communication Front End	X		X	X*		X
RTU	X		X	X*		X
IED (voltage)	X		**X**	**X***		**X**
IED (current)	X		**X**	**X***		
PDC						X
PMU				**X***		X
AMI Head-End						X
DER						
Communication Front End	X	X	X		X	X
DER Plant Controller	X	X	X			X
DER Controller	X	X	**X**		**X**	**X**
PMU or frequency transducer	**X**	**X**				

*) Only pre-emptive BSC. Component related to the observables are highlighted with red colour.

6 Conclusions

Concluding the task, it is interesting to have a look at one of the first conclusions which was made in one of the first deliverables in the present activity (see [1]): even though the WoC architecture is radically different from the conventional one, the identified observables appear to be very similar. It was pointed out that the reason for this is most likely the fact that they are both dependent on the same future scenario. This means that they answer to the same challenges.

That time, the conclusion was based on very preliminary analysis and assumptions. After several years of development and refinement, the concept has far more concrete specification via a set of dedicated Use Cases. It has also been tested through simulations and lab implementation. The set of observables derived from the Use Cases includes fairly well-known functions, with one possible exception of Actual (instant) frequency, which has certain limitations. These limitations, however, do not affect the feasibility of the Web-of-Cells concept as such (see for details [8]).

Mapping of the observables of the Use Cases and further grouping of these into clusters has helped to uncover and understand similarities between these and narrow the scope from about 40 observables to 11 clusters. Assignment to clusters was based on the observables' topology level, their input signal and their corresponding (possible) component. It appears that distribution of the observables across UCs is very uneven. The Inertia Response Power Control (IRPC) is a very demanding and specific case with six dedicated clusters of observables. This result can be partially related to the fact that IRPC can be considered as an innovative and demanding set of control actions, since it arises from the expected critical decrease of mechanical inertia availability and it may involve very small time scales. The three remaining balance Use Cases appear to share three clusters of observables, while the Voltage Control Use Cases have only two clusters.

The observability-related mapping of all six Use Cases to the functional and components layers has provided a better overview and understanding of the clustering method. The following combination of components, related to all the Use Cases, into one single diagram in practice has suggested a proposal for physical implementation enabling more specific design for the observability-related part. The proposal of course is not final and has to be tested, verified and further developed, but so far it has not uncovered any obvious barriers that will make WoC implementation impossible. Furthermore, the components appear to be commonly used (i.e. "off the shelf" type of equipment);this strengthens again the viability of WoC as a concept.

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8 Disclaimer

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9 Annex 1: Mapping of the observables

Table 14 - Mapping of the observables (part I)

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
IRPC_01	RSE	Frequency gradient (ROCOF)	IRPC	A: IRPC_01, IRPC_02	Inertial response (power dynamic control)	CTL-0	CTS-0	ROCOF containment (local or within a cell)	Voltage waveform	PLL (or FLL) and IIR derivative observer
IRPC_02	RSE	Frequency gradient (ROCOF)	IRPC	A: IRPC_01, IRPC_02	Inertial response (power dynamic control)	CTL-1	CTS-0	ROCOF containment (local or within a cell)	Voltage waveform	PLL (or FLL) and IIR derivative observer
IRPC_03	RSE	"Equivalent" inertia time constant of DER	IRPC	B: IRPC_03, IRPC_04, IRPC_05	Inertial response (power dynamic control)	CTL-2	CTS-3	ROCOF containment within a cell	Plant/device operational (or market) data	
IRPC_04	RSE	"Equivalent" inertia time constant of aggregated resources	IRPC	B: IRPC_03, IRPC_04, IRPC_05	Inertial response (power dynamic control)	CTL-2	CTS-3	ROCOF containment within a cell	Plant/device operational (or market) data	
IRPC_05	RSE	Inertia time constant of conventional machine	IRPC	B: IRPC_03, IRPC_04, IRPC_05	Inertial response (power dynamic control)	CTL-2	CTS-3	ROCOF containment within a cell	Plant/device operational (or market) data	
IRPC_06	RSE	"Equivalent" inertia time constant of DER	IRPC	C: IRPC_06, IRPC_07, IRPC_08	Inertial response (power dynamic control)	CTL-0	CTS-3	ROCOF containment within a cell	Cell operator (or market) decision	

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
IRPC_07	RSE	"Equivalent" inertia time constant of aggregated resources	IRPC	C: IRPC_06, IRPC_07, IRPC_08	Inertial response (power dynamic control)	CTL-1	CTS-3	ROCOF containment within a cell	Cell operator (or market) decision	
IRPC_08	RSE	Inertial time constant of conventional machine	IRPC	C: IRPC_06, IRPC_07, IRPC_08	Inertial response (power dynamic control)	CTL-0	CTS-3	ROCOF containment within a cell	Cell operator (or market) decision	
IRPC_09	RSE	"Equivalent" inertia time constant of cell	IRPC	D: IRPC_09, IRPC_10	Synchronous area inertia controller	CTL-2	CTS-3	"Equivalent" inertia procurement for ROCOF containment within WoC	Cell operational (or market) data	
IRPC_10	RSE	"Equivalent" inertia time constant of WoC	IRPC	D: IRPC_09, IRPC_10	Synchronous area inertia controller	CTL-3	CTS-3	"Equivalent" inertia procurement for ROCOF containment within WoC	WoC operational (or market) data	
IRPC_11	RSE	"Equivalent" inertia time constant of cell	IRPC	E: IRPC_11, IRPC_12	Synchronous area inertia controller	CTL-2	CTS-3	"Equivalent" inertia procurement for ROCOF containment within WoC	WoC/cell operator (or market) decision	
IRPC_12	RSE	"Equivalent" inertia time constant of	IRPC	E: IRPC_11, IRPC_12	Synchronous area inertia controller	CTL-3	CTS-3	"Equivalent" inertia procurement for ROCOF	WoC (or market) decision	

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
		WoC						containment within WoC		
IRPC_13	RSE	Centre-of-inertia frequency - COIF	IRPC	F: IRPC_13, IRPC_14	COIF Observer	CTL-2	CTS-0	COIF observation	Voltage waveform	PLL (or FLL) and IIR derivative observer
IRPC_14	RSE	ROCOF of centre-of-inertia frequency	IRPC	F: IRPC_13, IRPC_14	ROCOF Observer	CTL-2	CTS-0	ROCOF observation	Voltage waveform	PLL (or FLL) and IIR derivative observer
FCC_01	SINTEF	Tie-line power	FCC	G: FCC_01, BRC_01, BRC_03, BSC_04	Imbalance Observation	CTL-2	CTS-0	Imbalance observation	Voltage/current waveform	Unknown
FCC_02	SINTEF	Frequency	FCC	H: FCC_02, BRC_02, BSC_02, BSC_03	Frequency Observation	CTL-0	CTS-0	Frequency observation	Voltage waveform	PLL
BRC_01	SINTEF	Tie-line power	BRC	G: FCC_01, BRC_01, BRC_03, BSC_04	Tie-line Active Powerflow Observation/Imbalance Determination	CTL-2	CTS-1	Collect and aggregated the tie-line observables and compare this against the cell setpoint to determine a cell balance error signal	Voltage/current waveform	Unknown
BRC_02	SINTEF	Frequency	BRC	H: FCC_02,	Frequency Observation	CTL-0	CTS-1	Collect and aggregated the tie-	Voltage waveform	PLL,DSOGI-FLL or FIR

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
				BRC_02, BSC_02, BSC_03				line observables and compare this against the cell setpoint to determine a cell balance error signal		
BRC_03	SINTEF	Tie-line power	BRC	G: FCC_01, BRC_01, BRC_03, BSC_04	Tie-line Active Powerflow Observation/Imbalance Determination	CTL-2	CTS-1	Collect and aggregated the tie-line observables and compare this against the cell setpoint to determine a cell balance error signal	Voltage/current waveform	Unknown
BSC_01	CRES	Amount of Imbalance (power)	BSC	J:	Imbalance Correction	CTL-2	CTS-2	Restoration of balance within a cell	Tie-lines active power and frequency	PI controller
BSC_02	CRES	Frequency	BSC	H: FCC_02, BRC_02, BSC_02, BSC_03	Frequency Observer	CTL-0	CTS-2	Frequency observation	Voltage waveform	PLL,DSOGI-FLL or FIR
BSC_03	CRES	Frequency	BSC	FCC_02, BSC_02, BSC_03, BSC_04, BSC_05, BSC_06, BSC_07	Frequency Observer	CTL-0	CTS-2	Frequency observation	Voltage waveform	DSOGI-FLL
BSC_04	CRES	Frequency	BSC	FCC_02, BSC_02,	Frequency Observer	CTL-0	CTS-2	Frequency observation	Voltage waveform	FIR

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
				BSC_03, BSC_04, BSC_05, BSC_06, BSC_07						
BSC_03	CRES	Frequency	BSC	H: FCC_02, BRC_02, BSC_02, BSC_03	Frequency Observer	CTL-0	CTS-2	Frequency observation	Voltage waveform	PLL,DSOGI-FLL or FIR
BSC_06	CRES	Frequency	BSC	FCC_02, BSC_02, BSC_03, BSC_04, BSC_05, BSC_06, BSC_07	Frequency Observer	CTL-0	CTS-2	Frequency observation	Voltage waveform	DSOGI-FLL
BSC_07	CRES	Frequency	BSC	FCC_02, BSC_02, BSC_03, BSC_04, BSC_05, BSC_06, BSC_07	Frequency Observer	CTL-0	CTS-2	Frequency observation	Voltage waveform	FIR
BSC_04	CRES	Tie-line power	BSC	G: FCC_01, BRC_01, BRC_03, BSC_04	Imbalance Observer	CTL-2	CTS-2	Imbalance observation	Voltage/current waveform	Matlab/Simulink phasors block

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
PVC_01	IEN	Node 3-phase voltage	PVC	I: PVC_01, PPVC_01, PPVC_02, PPVC_03	PVC Controller	CTL-0	CTS-0	Minimise transient voltage deviations	3 phase-to-phase voltage waveforms	RMS (moving average) on each ph-ph waveform and averaging between phases
PVC_02	IEN	R/X ratio	PVC	K:	PVC Impedance Estimator	CTL-0	CTS-1	Estimate grid impedance	3 phase voltage and current	least sqares optimization (see white-box desc. for details)
PPVC_01	SINTEF	Node 3-phase voltage	PPVC	I: PVC_01, PPVC_01, PPVC_02, PPVC_03	Cell observing/PPVC Controlling	CTL-0	CTS-0	Check if each cell node is in the regulatory safe band or not. If not, the PPVC Set-point Providing function will be executed	Real time voltage measurements	Voltage Magnitude/RMS calculation
PPVC_02	SINTEF	Node 3-phase voltage	PPVC	I: PVC_01, PPVC_01, PPVC_02, PPVC_03	Cell observing/PPVC Controlling	CTL-0	CTS-0	Check if each cell node is in the regulatory safe band or not. If not, the PPVC Set-point Providing function will be executed	Real time voltage measurements	Magnitude from PF simulation
PPVC_03	SINTEF	Node 3-phase	PPVC	I: PVC_01,	Cell observing/PPVC	CTL-0	CTS-0	Check if each cell node is in the	Real time voltage	Magnitude from simulated

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
		voltage		PPVC_01, PPVC_02, PPVC_03	Controlling			regulatory safe band or not. If not, the PPVC Set-point Providing function will be executed	measurements	grid in real-time (Opal-RT)
PPVC_04	SINTEF	Node 3-phase voltage	PPVC	L:	Short-term Forecast/State Estimator	CTL-2	CTS-3	State estimator with short-term forcast as input to OPF function	Real time voltage measurements	Unknown
PPVC_05	SINTEF	Node power measurement (P and Q)	PPVC	M:	Short-term Forecast/State Estimator	CTL-2	CTS-3	State estimator with short-term forcast as input to OPF function	Real time voltage and current measurements	Unknown
PPVC_06	SINTEF	Reactive power reserves of distributed generators	PPVC	N:	-	CTL-2	CTS-3	Proactive over/undervoltages mitigation	-	VSM - Voltage stability margin – relative amount of system load rise until voltage collapse is found as function of reactive power reserves.
PPVC_07	SINTEF	Tie line reactive	PPVC	O:	-	CTL-2	CTS-3	Proactive over/undervoltages	-	If information from outside

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
		power reserve						mitigation		the cell is lost, reactive power flow in the tie lines could be used as an observable, instead of Reactive power reserves of distributed generators
PPVC_08	SINTEF	Deviation in active and reactive power in tie-lines	PPVC	P:	-	CTL-2	CTS-1	Identify inter-cell loop flows	Active and reactive power	Deviation between active and reactive power setpoint and actual values in tie-lines
PPVC_09	SINTEF	Deviation in voltage and voltage angle in connection points	PPVC	Q:	-	CTL-2	CTS-1	Identify inter-cell loop flows	Voltage and voltage angle	Deviation between voltage and voltage angle setpoint and actual values in connection points between cells

ID nr	Responsible partner	Observable	Use Case, where it is applied	Similar observables, which can be grouped (ID nr)	Applied in Function(s) in the UC	Control level (CTL) for the measurement	Control Time Scales (CTS)	Control aim (of function?)	Observable input signal(s)	Observable algorithm description, reference
PPVC_10	SINTEF	OPF results: Active and reactive power in tie-lines	PPVC	R:	-	CTL-2	CTS-3	Reduce inter-cell loop flows by coordinating voltage set-points between cells and possible move production	Active and reactive power	Results from each step of the OPF
PPVC_11	SINTEF	OPF results: Voltage and voltage angle in connection points	PPVC	S:	-	CTL-2	CTS-3	Reduce inter-cell loop flows by coordinating voltage set-points between cells and possible move production	Voltage and voltage angle	Results from each step of the OPF

Table 15 - Mapping of the observables (part II)

ID no	Minimum time resolution for the input (sample frequency)	Minimum time resolution for the output (sample frequency)	Time resolution tested/implementation (sample frequency)	Maximum latency value required by the control (delay in measurement, computation, transmission etc.)	Actual latency caused by the observable algorithm	Actual latency tested (consider including reference to the actual implementations)	Reference location according to the network's voltage level (LV/MV/HV)	Reference location according to the network's topology	Possible input device /component
IRPC_01	1000 samples/s	50 samples/s	N/A	from <0.1 s up to 0.5 s	<0.1 s	0.1 s -10 s (latency > 0.1 s: visible negative effects on control performance)	LV/MV/HV	Buses or other DER devices	Voltage measurement transformer or PLL itself
IRPC_02	1000 samples/s	50 samples/s	N/A	from <0.1 s up to 0.5 s	<0.1 s	0.1 s -10 s (latency > 0.1 s: visible negative effects on control performance)	LV/MV/HV	Buses (one or more) or aggregated DER devices	Voltage measurement transformer or PLL itself
IRPC_03							LV/MV/HV	Buses or other DER devices	info transmitted by the resource to the cell operator
IRPC_04							LV/MV/HV	Buses or aggregated DER devices	info transmitted by the resource to the cell operator
IRPC_05							LV/MV/HV	Buses of conventional power plants	info transmitted by the resource to the cell operator
IRPC_06							LV/MV/HV	Buses or other	info transmitted

ID no	Minimum time resolution for the input (sample frequency)	Minimum time resolution for the output (sample frequency)	Time resolution tested/implementation (sample frequency)	Maximum latency value required by the control (delay in measurement, computation, transmission etc.)	Actual latency caused by the observable algorithm	Actual latency tested (consider including reference to the actual implementations)	Reference location according to the network's voltage level (LV/MV/HV)	Reference location according to the network's topology	Possible input device /component
								DER devices	by the cell operator to the resource
IRPC_07							LV/MV/HV	Buses or aggregated DER devices	info transmitted by the cell operator to the resource
IRPC_08							LV/MV/HV	Buses of conventional power plants	info transmitted by the cell operator to the resource
IRPC_09									
IRPC_10									
IRPC_11									
IRPC_12									
IRPC_13	1000 samples/s	50 samples/s	N/A	<0.1 s	<0.1 s	0.1 s -10 s (latency > 0.1 s: visible negative effects on control performance)	LV/MV/HV	Buses or other DER devices	Voltage measurement transformer or PLL itself
IRPC_14	1000 samples/s	50 samples/s	N/A	<0.1 s	<0.1 s	0.1 s -10 s (latency > 0.1 s: visible negative	LV/MV/HV	Buses or other DER devices	Voltage measurement transformer or

ID no	Minimum time resolution for the input (sample frequency)	Minimum time resolution for the output (sample frequency)	Time resolution tested/implementation (sample frequency)	Maximum latency value required by the control (delay in measurement, computation, transmission etc.)	Actual latency caused by the observable algorithm	Actual latency tested (consider including reference to the actual implementations)	Reference location according to the network's voltage level (LV/MV/HV)	Reference location according to the network's topology	Possible input device /component
						effects on control performance)			PLL itself
FCC_01	1000samples/sec	1sample/sec	N/A	<1sec	<1msec	N/A	Mainly MV and LV	Tie-line buses	Active power transducer, PMU
FCC_02	1000samples/sec	5sample/sec	N/A	<1sec	<1msec	N/A	Mainly MV and LV	Buses or other DER devices	PMU
BRC_01	1000samples/sec	1sample/sec	N/A	<1sec	<1msec	N/A	Mainly HV and MV	Tie-line buses	Active power transducer, PMU
BRC_02	1000samples/sec	1sample/sec	N/A	<1sec	<1msec	N/A	Mainly MV and LV	Buses or other DER devices	PMU
BRC_03	N/A	Real time	N/A	N/A	N/A	N/A	Mainly HV and MV	Tie-line buses	Active power transducer, PMU
BSC_01	1sample/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	N/A	All Voltage Levels apply	Tie-line buses	PMU/RTU
BSC_02	1000samples/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	The latencies tested for the different algorithms were	Mainly MV and LV	Buses or other DER devices	PMU

ID no	Minimum time resolution for the input (sample frequency)	Minimum time resolution for the output (sample frequency)	Time resolution tested/implementation (sample frequency)	Maximum latency value required by the control (delay in measurement, computation, transmission etc.)	Actual latency caused by the observable algorithm	Actual latency tested (consider including reference to the actual implementations)	Reference location according to the network's voltage level (LV/MV/HV)	Reference location according to the network's topology	Possible input device /component
						indirectly related to the circuit parameters			
BSC_03	1000samples/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	The latencies tested for the different algorithms were indirectly related to the circuit parameters	Mainly MV and LV	Buses or other DER devices	PMU
BSC_04	1000samples/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	The latencies tested for the different algorithms were indirectly related to the circuit parameters	Mainly MV and LV	Buses or other DER devices	PMU
BSC_03	1000samples/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	The latencies tested for the different algorithms were indirectly related to the circuit parameters	Mainly MV and LV	Buses or other DER devices	PMU

ID no	Minimum time resolution for the input (sample frequency)	Minimum time resolution for the output (sample frequency)	Time resolution tested/implementation (sample frequency)	Maximum latency value required by the control (delay in measurement, computation, transmission etc.)	Actual latency caused by the observable algorithm	Actual latency tested (consider including reference to the actual implementations)	Reference location according to the network's voltage level (LV/MV/HV)	Reference location according to the network's topology	Possible input device /component
BSC_06	1000samples/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	The latencies tested for the different algorithms were indirectly related to the circuit parameters	Mainly MV and LV	Buses or other DER devices	PMU
BSC_07	1000samples/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	The latencies tested for the different algorithms were indirectly related to the circuit parameters	Mainly MV and LV	Buses or other DER devices	PMU
BSC_04	1000samples/sec	1sample/sec	>1000samples/sec	<1sec	<1msec	N/A	Mainly HV and MV	Tie-line buses	Active power transducer
PVC_01	5000 samples/s	5000 samples/s	5000 samples/s	1 ms	100 samples * 200 us = 20 ms for maximum accuracy	200 us	MV	generator bus (synchronous generator of e.g. conventional power plant)	Voltage transformer
PVC_02	1 ms	~100 ms	1 ms	up to 500 ms (depending on internal parameters)	several tens of ms	N/A	LV	generator bus	Voltage transducer and current transducer

ID no	Minimum time resolution for the input (sample frequency)	Minimum time resolution for the output (sample frequency)	Time resolution tested/implementation (sample frequency)	Maximum latency value required by the control (delay in measurement, computation, transmission etc.)	Actual latency caused by the observable algorithm	Actual latency tested (consider including reference to the actual implementations)	Reference location according to the network's voltage level (LV/MV/HV)	Reference location according to the network's topology	Possible input device /component
PPVC_01	1 sec proposed		-	Not given - should not be any problem	(depends on the time range for calculation the mean value of the RMS voltage)	-	Mainly MV and LV	Buses	PMU, RTU etc.
PPVC_02	-		Every minut	-	-	-	Mainly MV and LV	Buses	PF simulation
PPVC_03	-		Every minut	-	-	-	Mainly MV and LV	Buses	Opal-RT
PPVC_04	Each 15 min or trigging of PPVC Set-point providing		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.
PPVC_05	Each 15 min or trigging of PPVC Set-point providing		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.
PPVC_06	Each 15 min or trigging of PPVC Set-point providing		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.
PPVC_07	Each 15 min or trigging of PPVC Set-point providing		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.

ID no	Minimum time resolution for the input (sample frequency)	Minimum time resolution for the output (sample frequency)	Time resolution tested/implementation (sample frequency)	Maximum latency value required by the control (delay in measurement, computation, transmission etc.)	Actual latency caused by the observable algorithm	Actual latency tested (consider including reference to the actual implementations)	Reference location according to the network's voltage level (LV/MV/HV)	Reference location according to the network's topology	Possible input device /component
PPVC_08	Minute		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.
PPVC_09	Minute		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.
PPVC_10	Each 15 min or trigging of PPVC Set-point providing		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.
PPVC_11	Each 15 min or trigging of PPVC Set-point providing		-	-	-	-	Mainly MV and LV	Buses	PMU, RTU etc.

Table 16 - Mapping of the observables (part III)

ID nr	Time stamp (yes/no)	Maximum accuracy	Actual accuracy	Requirements to the communication channel	Is the observable communicated to another use case or component	If yes, from where	To where	Commonly used/regular practice observable (yes/no)
IRPC_01	No	0.001Hz/s	0.001Hz/s	none - local measurement	No			No
IRPC_02	No	0.001Hz/s	0.001Hz/s	none - local measurement	No			No

ID nr	Time stamp (yes/no)	Maximum accuracy	Actual accuracy	Requirements to the communication channel	Is the observable communicated to another use case or component	If yes, from where	To where	Commonly used/regular practice observable (yes/no)
IRPC_03	No			info transmitted by the resource to the cell operator	No			No
IRPC_04	No			info transmitted by the resource to the cell operator	No			No
IRPC_05	No			info transmitted by the resource to the cell operator	No			No
IRPC_06	No			info transmitted by the cell operator to the resource	No			No
IRPC_07	No			info transmitted by the cell operator to the resource	No			No
IRPC_08	No			info transmitted by the cell operator to the resource	No			No
IRPC_09								No
IRPC_10								No
IRPC_11								No
IRPC_12								No
IRPC_13	No	0.001Hz	0.001Hz	none - local measurement	No			No
IRPC_14	No	0.001Hz	0.001Hz	none - local measurement	No			No
FCC_01	No	1 Watt	1 Watt	N/A	No			No
FCC_02	No	0.01Hz	0.01Hz	N/A	No			Yes
BRC_01	No	1 Watt	1 Watt	N/A	No			No
BRC_02	No	0.01Hz	0.01Hz	N/A	No			Yes

ID nr	Time stamp (yes/no)	Maximum accuracy	Actual accuracy	Requirements to the communication channel	Is the observable communicated to another use case or component	If yes, from where	To where	Commonly used/regular practice observable (yes/no)
BRC_03	No	N/A	N/A	N/A	No			No
BSC_01	No	1Watt	1Watt	N/A	Yes	BSC	BRC	No
BSC_02	No	0.01Hz	0.01Hz	N/A	Yes	BSC	FCC	Yes
BSC_03	No	0.01Hz	0.01Hz	N/A	Yes	BSC	FCC	Yes
BSC_04	No	0.01Hz	0.01Hz	N/A	Yes	BSC	FCC	Yes
BSC_03	No	0.01Hz	0.01Hz	N/A	Yes	BSC	BRC	Yes
BSC_06	No	0.01Hz	0.01Hz	N/A	Yes	BSC	BRC	Yes
BSC_07	No	0.01Hz	0.01Hz	N/A	Yes	BSC	BRC	Yes
BSC_04	No	1 Watt	1 Watt	N/A	Yes	BSC	BRC	Yes
PVC_01	No	0,00003051757813	0.5% of generator voltage	N/A	Yes	PVC Controller	PPVC Controlling	Yes
PVC_02	No (Yes possible)	0.01 pu	N/A	N/A	Yes	PVC Impedance Estimator	PVC Controller	No
PPVC_01	no	-	-	-	yes	Bus	PPVC	yes
PPVC_02	no	-	-	-	yes	PF simulation	PPVC	yes
PPVC_03	no	-	-	-	yes	Opal RT	PPVC	yes
PPVC_04	yes	-	-	-	yes	Bus	PPVC	yes
PPVC_05	yes	-	-	-	yes	Bus	PPVC	yes
PPVC_06	yes	-	-	-	yes			no
PPVC_07	yes	-	-	-	yes			no

ID nr	Time stamp (yes/no)	Maximum accuracy	Actual accuracy	Requirements to the communication channel	Is the observable communicated to another use case or component	If yes, from where	To where	Commonly used/regular practice observable (yes/no)
PPVC_08	yes	-	-	-	yes			no
PPVC_09	yes	-	-	-	yes			no
PPVC_10	yes	-	-	-	yes			no
PPVC_11	yes	-	-	-	yes			no

10 Annex 2: Pan-European observables

The previous activity "Observables for Pan-European Control Schemes" focused on deriving power system observables for high voltage systems [11]. The different observables have been derived by analysing traditional instability phenomena typical of large power systems and the findings are here summarized. The conducted studies were focused on novel observability concepts at the system-wide scale: observables necessary for the novel WoC-based control methods have been developed, to enable proper operation both within cells and at inter-cell level.

Considering the Pan-European level these observables are essential for assessment of assessments on the system level and therefore are important for overall implementation of the concept. They are not however directly included into the Balance and Voltage Control Use Cases.

The main results obtained can be summarized as follows.

10.1 Cell/system transient stability (large disturbance stability)

An approach to assess transient stability on a system-wide level and visualize the results appropriately was introduced. Transient stability is assessed by means of observed voltage angles rather than rotor angles and, therefore, the method can also be applied under presence of high share of converter based generation. The results are presented in a bar plot with dedicated colouring in order to facilitate the visual examination. Future work will concern determining the most critical buses to be analysed and define preventive actions to resolve potential stability issues.

10.2 Small signal cell stability with focus on inter-cell oscillations (small disturbance stability)

The proposed method for small signal cell stability assessment, with focus on inter-cell oscillations, is based on real-time mode damping estimation of voltage angle differences between cells, using Prony's Method. Derived observables, as oscillation mode amplitude, frequency, damping and energy could be used for providing power system control room operators with adequate indicators of the stress of their network and prevent power system swing with proper actions. The results are presented for three examples with different low-frequency mode behaviour. However, additional work has to be done regarding “dominant inter-cell oscillation path” determination, a concept based on the notion of interaction paths. These dominant inter-cell oscillation paths are deterministic and algorithms for their identification using both models and measurements are available. Signals from the dominant path are the most observable and have the highest content of inter-cell modes. This suggests that by using well-selected dominant path signals for wide-area control, adequate damping performance can be achieved.

10.3 Inertia at Pan-European level

A reduced amount of mechanical inertia causes fast and wide unbalancing, and therefore frequency, variations. This calls for the need of measuring not only the frequency, but also its time derivative i.e. the ROCOF, which is a new observable. Prompt control actions (synthetic inertia) in each cell can be introduced based on the local ROCOF measurement. Measurement performance requirements in terms of acquisition and elaboration latency and of output precision have to be considered, in order to have correct frequency and ROCOF estimates for effective (and possibly fast) control purposes as well as avoid inadvertent protection system interventions. Both at cell and inter-cell level, the amount of available inertia also has to be monitored, as a further new observable, and cells have to procure sufficient reserves - from resources endowed with physical inertia and/or synthetic inertia - in order to support short-term frequency stability.

10.4 Voltage stability (transmission capacity)

The proposed method for voltage stability margin (VSM) assessment is based on reactive power reserves monitoring. For the best VSM estimation all available VAR resources, i.e. reactive power resources, are monitored and equivalent reactive power reserve is calculated, assigning each resource a calculated weighting factor. In case distant measurements are not available (cell perspective) VAR measurements of inter-cell lines substitute them providing necessary information for VSM calculation.

10.5 Inter-cell loop flows

An inter-cell loop flow is a physical phenomenon that occurs when there is a difference between commercial schedules and physical flows of power between the producers and the customers. OPF simulations on the Pan-European circuit in PowerFactory show that inter-cell loop flows could be avoided by using an overall OPF (on the whole Woc). In this case, the minimum total losses are obtained. However, the PPVC in ELECTRA should not contain a CTRL-3 (inter-cell) level, and the OPF must be performed at a cell level, causing higher losses and inter-cell loop flows. By exchanging observables, like active and reactive power in tie-lines between neighbour cells and voltage magnitude and angle at the connection point, between each iteration of the OPF, the neighbour cells could agree on the voltage at the connection points and power flow in the lines, avoiding inter-cell loop flows. Two methods are suggested: “consensus-based distributed OPF” and “Token Ring distributed control for OPF”.