# D 3.2 SYSTEM ARCHITECTURE

## VERSION 1

Oliver Kraft
Oliver Pohl
Florian Rewald

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| **Author(s)** | 2021-05-21 | Oliver Kraft | ie3, TU Dortmund |
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## LIST OF ABBREVIATIONS

| Abbreviation | Definition |
|---|---|
| **AMI** | Advanced metering infrastructure |
| **BG** | Balance Group |
| **BRP** | Balance Responsible Party |
| **D** | Deliverable |
| **DER** | Distributed energy resource |
| **DIN** | German Institute for Norming |
| **DMS** | Distribution Management System |
| **DS** | Distribution System |
| **DSO** | Distribution System Operator |
| **EHV** | Extra high voltage |
| **EMS** | Energy management system |
| **EV** | Electric vehicle |
| **FO** | Flexibility Operator |
| **GCP** | Grid connection point |
| **HES** | Head-end system |
| **HMI** | Human machine interface |
| **HV** | High voltage |
| **ICT** | Information and communication technology |
| **ISR** | Imbalance Settlement Responsible |
| **IT** | Information technology |
| **LV** | Low voltage |
| **MO** | Market Operator |
| **MV** | Medium voltage |
| **OPF** | Optimal power flow |
| **OTC** | Over the counter |
| **PV** | Photovoltaic |
| **RES** | Renewable Energy Source |
| **SGAM** | Smart-Grid-Architecture-Model |
| **SO** | System Operator |
| **TS** | Transmission System |
| **TSO** | Transmission System Operator |
| **WP** | Work Package |

# 1 INTRODUCTION

## 1.1 Objective

The ERA-Net funded project HONOR – holistic flexibility market integration of cross-sectoral energy sources – covers the development and evaluation of a trans-regional flexibility market mechanism, integrating cross-sectoral energy flexibility at a community-wide level. Deliverable (D) 3.2 aims at creating a holistic system architecture for further work in the project towards the flexibility market design and the technical assessment. The system architecture covers the core business roles towards creating the flexibility market in the project and their relations on different system layers. The elaboration focuses on mapping the proposed architecture on the Smart Grid Architecture Model (SGAM) [1].

D3.2 is part of Work Package (WP) 3, which deals with the creation and evaluation of the system architecture. The identified use cases in D3.1 [2] are used as input and the architecture has to allow for a mapping of these. D2.1 delivered results from a stakeholder workshop and presented questionnaires on the requirements and expected benefits of flexibility markets, which are also used as input. D3.2 then serves as a preparation for D3.3 and D3.4 in which the architecture will be completed with data streams and technical system layers. The results from WP3 are used in the wider context of the project for the following WPs on market modelling (WP4), control system development (WP5), cyber-physical system monitoring (WP6), and cyber-security modelling (WP7). In WP4, the market design should provide more insight on the topics that were left open in D3.2. For WP6 and WP7, a more detailed architecture is created that focuses on the technical structure and data streams [3]. In the end, a holistic system with the required regulatory and technical components for the implementation of a flexibility market will be in place, that will also be verified in laboratory environment and through a field application (WP8). An overview on the WPs and the project's structure is given in Figure 1.

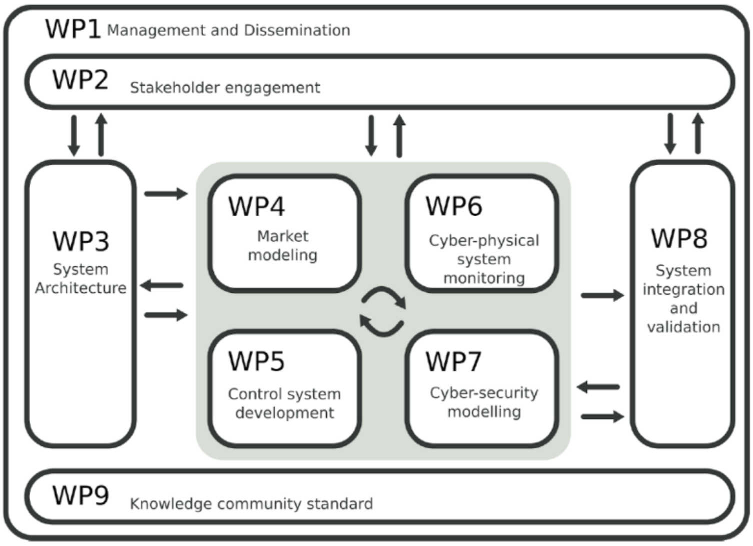


Figure 1: HONOR Work Package overview

## 1.2 Scope

For D3.2, the targeted system in HONOR is analysed considering the required components. The project features an interdisciplinary challenge through its wide coverage of contents from regulatory framework and market design to cyber-physical components and control systems. Therefore, D3.2 and WP3 in general aim at delivering a base for further work in the project. Furthermore, the different WPs partly include dependencies on general topics from other WPs. WPs with special focus on flexibility market design. From the scope perspective, WP4 focuses on development of the overall concept, corresponding methods, and performance evaluation, whereas rest of the WPs partly rely on the market to continue the work on technical facets. D3.2 therefore also aims at covering topics with dependencies between WP4-WP7 and defining the solutions in the context of HONOR. In addition, further elaborations towards the topic of flexibility are added from the market perspective and for technical applications. These were part of various discussions in the project consortium towards creating this architecture and settling on core definitions for ongoing research. D3.2 is capped off with the developed system architecture.

## 1.3 Approach and structure

D3.2 is highly based on the regulations in the related DIN SPEC 91410-1 by the German institute for norming (DIN) [4]. The document presents guidelines and requirements for flexibility markets as a part of future congestion management in power systems. It has been created in the process of the corresponding SINTEG research projects with universities and industrial partners like transmission and distribution system operators (TSOs, DSOs). The DIN SPEC can be seen as a "pre-norm" with guidelines for future work on flexibility markets, which is required to continue the research towards creating solutions for volatile power systems.

As the creation process of the system architecture evolved through working on the topic of flexibility markets and their requirements, aspired targets, existing concepts, and regulatory relation, D3.2 presents an elaboration on the discussion in section 2. Afterwards, the overall requirements for the technical infrastructure are presented in section 3, though WP5, WP6 and WP7 will extend the elaborations on a technical level. The proposed system architecture will then be presented in section 4 with the corresponding SGAM layers, before a conclusion and outlook follow in the last section.

# 2 FLEXIBILITY MARKET APPROACHES

## 2.1 Demand for novel market concepts

Through the transition from fossil power plants to an increasing share of decentralized energy resources (DERs), the European power system faces new challenges through the changing grid utilisation. The volatile feed-in of DERs and the rising inclusion of assets with less predictable behaviours, like heat pumps and electric vehicles in subordinate voltage levels, increases the uncertainty for a safe system operation. While this has an effect on market actions for short term portfolio balancing by balance responsible parties (BRP), it also results in a growing demand for a short-term adjustment of grid assets to relieve pending grid congestion and the violation of network restrictions. This short-term adjustment of a unit's operating point for grid or market purposes can be defined as *flexibility*.

While currently market-based flexibility is being traded on centralized power exchanges or via over the counter (OTC) trades in the existing market framework, the flexibility for grid purposes creates more challenges for TSOs and DSOs and their power systems. While the TSO accesses the reserve market for frequency control, the different system operators (SO) cooperate on the location based congestion management. This includes the adjustment of power plants and (starting in October 2021 in Germany [5]) also the curtailment of controllable DERs. Even for congestion in the transmission system (TS), the range of activated units extends all the way to lower voltage levels. With the increasing share of DERs and the shutdown of fossil power plants, the demand for flexibility from lower voltage levels will expand much further in the future. After performing a DER curtailment or increase according to the current and upcoming regulations, the asset owner is compensated. However, this currently does not include the majority of the demand side through load shifting or curtailment and the flexibility from small units that may require further control components. Furthermore, the SO cannot monetarily assess the pricing of such products and therefore there is no regulatory framework to force such control actions on the assets. While some countries already have fitting consumer schemes with reduced payments, it is not yet adapted on a larger scale. This results in an undefined quantity of flexibilities, which are currently not exploited trough the lacking technical infrastructure or the lacking economic efficiency [6].

Trends for the future power system indicate a need for changes in the existing structure. The decentralized distribution of units results in a distribution system (DS) utilisation, which these subordinate voltage levels were not designed for when created initially. This is especially critical considering the limited system monitoring and the costly and time-consuming nature of physical grid expansion. Since the utilisation of LV and MV grids will further increase through more units and a demand for flexible operation, the need for better system monitoring and additional flexibility options will grow accordingly. In the process, more flexibility options have to be exploited. This primarily includes small units like storages, heat pumps, electric vehicles, and loads. In order to integrate this into the present power system framework, changes have to be made.

A possible implementation is visualized in Figure 2 by adding a local flexibility market. On the flexibility demand side, the conventional congestion management through unit curtailment with compensation fees gets either fully or partially replaced with the flexibility market as a market-based congestion management. Therefore, flexibility for grid usage can be purchased by the SO depending on the location in the network. On the flexibility provision side, the exploited flexibility potential extends significantly, since various flexible products can be offered on a flexibility market according to the flexibility operator's (FO) compensation expectations. This solves the issue of the monetary assessment and the missing regulations to force control actions on such units.

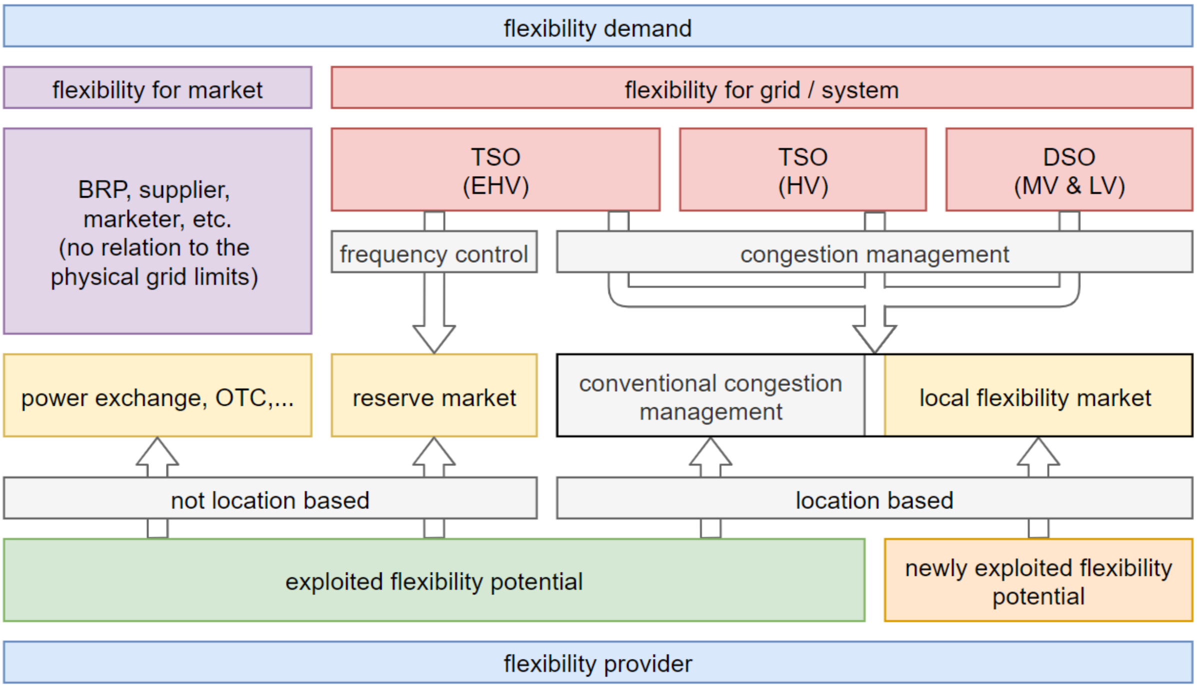


Figure 2: Future concept for flexibility use in Germany (based on [4])

## 2.2 Concepts for market design

The key concepts listed in this section need to be accounted for in the system architecture. Contents towards the market necessity, structure, roles and their respective relations are elaborated in the general context of flexibility markets.

**Introduction and traffic light:**

Flexibility markets primarily focus on a regionalized concept for trading flexibility locally between SO and FO to relieve congestion in the power system. The FO can be an aggregator, who markets and operates a pool of assets, or an owner of large flexible assets. While different concepts for the market design exist, a widespread approach is that the TSO and DSO work in cooperation to determine the flexibility demand and then partly serve as market operators (MO), which is feasible as they are the only buyers on this platform [7]. Since various market designs differ on the exact coordination between TSO and DSO, the role is furthermore summarized by referring to them together as the

SO. If the SO's forecasts do not predict a pending congestion, there is no need for the local flexibility market and flexibility can then be offered for system-level balancing services. For coordinating the need for the flexibility market to open and close, the BDEW traffic light model defines three potential system states [8]. During the green state, there is no pending congestion or it can be resolved through the SO's internal measures and therefore no need for the activation of a flexibility market in advance. During the yellow phase, the SO estimates congestion and activates the local flexibility market. In addition to the mentioned options, the traffic light concept also includes a red phase, which is activated, if there is an imminent risk for system stability so that the SO imposes full control and performs curtailment and potential load shedding themselves. This curative adjustment is concluded with compensation fees for the concerned parties.

**Problems of the current structure:**

The flexibility market presents an addition to the existing, centralized power exchanges and the reserve market. The exchanges allow energy trades between various parties like suppliers and marketers and deliver the economic optimum in a bidding zone with no consideration to the physical grid capacities. This results in unit schedules, which the grid may not be able to transmit and since the required network expansion cannot hold pace with the rising share of DER and other units being integrated in the network, the market result has to be adjusted to the grids capacities. This subsequent adjustment is associated with large costs, which are rising every year in proportion to the newly integrated units [5]. To close the gap between the economic optimum and the associated curtailment costs, local flexibility markets aim at solving this problem through a market-based approach with its incentives and competition, while efficiently helping the SO with congestion. Aside from these two platforms, the reserve market for frequency control may also play a role as pooled DERs can be used for frequency control as well and the network capacity has to allow such activation. Either way, a full framework for coordinating these markets and the resulting processes is required. [9]

**Demand and co-existence of markets:**

The framework for combining the stated markets requires a fitting structure to allow these platforms to fulfil their tasks and not cause major interferences between each other. This challenge is hinted at in Figure 2 and includes various problems, especially between the central power exchanges and the new flexibility markets. It starts off with the flexibility provider's placement of offers. On the power exchange, the offers are placed without location information and in the case of small DERs in subordinate voltage levels, often in pooled products of multiple units by the TSOs. This fully contradicts with local markets, where the location is crucial for a transaction and even smaller units may have to be activated separately instead of all units in a pool, depending on the addressed congestion range of the local market. While this problem may be solved for flexibility from small assets like electric vehicles, where marketing on a central exchange is not possible due to verification and reliability issues, it is very present with DERs, which have a high relevance for central and local platforms. This has to be dealt with and some approaches continue to use conventional congestion management with compensation according to the initial selling price of a units' power. This fully eliminates the participation of these units on local flexibility platforms. [10]

**Inc-Dec-Gaming:**

While the regulatory framework and the general coordination of a novel flexibility market is challenging, it is especially prone to Inc-Dec-Gaming. Per definition this stresses the strategic behaviour of market participants on the spot market by anticipating revenue from congestion management and therefore maximizing their overall profit [11]. A prime example covers the seller of a generation unit anticipating congestion and pricing far over market value to avoid getting matched on the spot market. Afterwards a profit can be generated from the resulting congestions, which can be solved by adjusting the setpoint of the sellers' generation unit for a high price. Even though such behaviour is rewarding for the seller, it massively reduces the overall system economics resulting in higher costs for the SO and eventually higher costs for the end consumers. It is aspired to avoid these effects as far as possible. With flexible markets opening a new platform with even more freedom to participants than through regulated congestion management, the relevance for supressing this system harming behaviour increases. To assess the significance, further research and simulation has to be carried out. While some studies profess an uncontrollable amount of gaming problems [11], others show that a practical execution of market manipulation is only possible in a limited and acceptable amount [6]. The evaluation very much depends on the chosen assumptions, especially considering an entity's knowledge and the overall predictability of the power system. If a FO can precisely estimate every congestion and the schedule of other units, the FO can emphasize a financial gain through gaming. Since this is barely realistic in practice and also includes the risk of not selling energy at all, its relevance may diminish [6]. Either way, the gaming problem will need further research and a regulatory vigilance to monitor and prevent the behaviour.

**Timeslots for market:**

Another challenge is the time horizon and the closure times of these two markets. The power exchange market closes between 30 and 5 minutes before delivery depending on the regional location of trade partners [5]. Since the flexibility market is based on a congestion prognosis, whose deviation decreases over time, a late market closure is pursued as well. One approach sees the flexibility market closing after the spot market. This could solve the problem on the providers side as unmatched offers on the spot market can serve for the local markets afterwards. The location component may be kept hidden by independent roles and only made public to the SO once the flexibility market opens after the closure of the power exchange market. The stated concept is realized in the Dutch flexibility market GOPACS and further assessments would be necessary for an efficient implementation [11]. Nevertheless, this is just one potential realization as the timely overlapping co-operation of the flexibility market and the central exchange market also comes with additional balancing hurdles and may have to be realized through other concepts, which will be addressed in the following subsections.

**BRPs relation to flexibility markets:**

A major problem is the way activation of local flexibility affects the system balance in balancing groups (BGs) which are operated by a balance responsible party (BRP). The BRPs create forecasts for their generation and loads and purchase or sell the deviation on the central market in order to balance their portfolio. If the summed deviation of all BG in a control area is not equal to zero, the TSO accumulates the deviation costs and depending on a BG and the whole control area being under or over supplied, the BRPs get charged in the process. Either way, the BRPs aspire a minimal deviation from their schedule for minimizing their costs long term and obviously keeping the frequency in the entire system at its level through the physical balancing. In addition to the existing mechanisms, the flexibility markets now present an intervention towards these structures.

**Role of the Aggregator:**

First of all, the role definitions considering BRPs and FOs and the resulting relations have to be specified. As previously stated, the BRP's core task is to manage their pool of generation and loads and sell or purchases the deviations. The FO now has the target to make a profit from flexibility trading and can be an owner of a flexible asset, or an aggregator, as stated in section 2.1. Since these aggregators most likely do not just wait for the yellow traffic light phase to get active on the local market, they can operate on the centralized power exchanges, if their pool size, reliability and financial capacities allow for it (market entrance fee and yearly fee). This however presents a barrier in practice, as smaller FOs often do not match the requirements to access the spot market. Independent of the market relation, the FO's assets have to be contracted under a BRP. For asset owners who market their flexibility themselves, the BRP has to allow them to trade flexibility in a contract agreement. This could result in a problematic framework, if the different assets of an aggregator are contracted to various BRPs. If the aggregator is a BRP themselves, the balancing has to be managed internally. [12]

**Balancing in current congestion management:**

The BRPs relation to the current congestion management should be taken as a reference, though the upcoming regulations in Germany are already considered. The conventional congestion management is realized through balanced measures by the SO with no deviations in terms of the system's feed-in and load balance. Even the feed-in management has to be balanced by the SO according to the novel legislation [5]. So if, for example, a generation unit is curtailed at some point in the grid, there has to be a counterpart by increasing the generation from another unit or by reducing the load at another point. For the case of line overloading, this is done geographically "before" and "after" the congestion in the network structure.

**Balancing approaches for local flex markets:**

A congestion reaction through a flexibility market has to result in balanced interventions as well in order to avoid increasing reserve utilisation and frequency problems in the power system. A practical solution would cover that by splitting the local flexibility trading entirely from balancing the BG and transferring that task to the SO purchasing flexibility, like in the upcoming legislation for feed-in management [5]. This would decouple congestion management from the BRPs balancing and present a feasible solution, if the verification process is specified further. This especially covers the assessment of a units' real power output after operation, when the BRPs baseline is changed through flexibility activation and initial deviations may not be measurable.

However, the current regulation approaches in Germany do not see this as being the duty of the activating SO and rather supports the idea of the flexibility market closing before the intraday market and committing the BRP to balance the imbalances caused by the FO [4]. This means, that the imbalance caused by the FO and their local flexibility trading forces the BRP to head to the spot market for balancing his portfolio. For short term flexibility trades, the BRP would be exposed to high prices on the intraday market and the overall economic state of the system would get worse through the large number of expensive transactions having to be made by the BRPs. This is also critical considering these balancing trades not respecting the grid's capacities and potentially causing congestion once more. The extended effects of that would have to be analysed in extensive market simulations. Internal balancing mechanisms from BRP providers with a large BG coverage may deliver a possible solution as well.

The opposing idea, stating balancing being in the hand of the SO, would include the necessity of a concept to coordinate the physical balancing of the resulting power deviations between the SOs. An often desired approach in literature features a cellular modelling of the power system where the grid is divided in different cells and layers depending on the voltage level and topology. The cellular modelling then desires a balancing and potential self-supply of the cell [13]. A potential realization of this would be, that each SO has to purchase flexibilities with a power delta of zero or by additional trades within the cell. However, if every local DSO would do that for their own cell as a part of a national power system, the nationwide economic costs would increase due to the insufficient approach of balancing each cell on its own. For that reason, the balancing of different flexibility activations has to allow for a mutual compensation between grid areas with an increase and grid areas with a decrease of power injection. All this shall of course be within the grid's capacities. The closer the cooperation between all the affected SOs, the better the solution will be. For example, one DSO could solve congestion by reducing a feed-in, while another DSO opts for reducing a load as a consequence to keep the summed costs for both DSOs smaller, instead of the more expensive approach where both DSO curtail feed in and have to come up with balancing actions on top. The required

SO optimization would possibly extend to a separate research area because of its complexity and is further examined in WP4.

**Outlook and further solutions:**

The general problem of the market not respecting the grid's capacity, which ultimately results in novel concepts with flexibility markets and congestion management being researched, can possibly be solved on a higher level. In literature, a number of larger scale approaches can be found [14]. This primarily covers an overhaul of the existing market structures and common examples are nodal pricing and zonal energy prices, rather than one bidding zone, like it is currently in most European countries. In [5], it is stated, that a single bidding zone is the better solution, unless the costs for congestion management increase significantly, which is currently happening and even intensified by the growing electrisation of the traffic and heating sectors [14]. For a newly designed power system, where the market recognizes the grids' capacities, these options would present an economically better solutions [9]. Its downside is shown in the effects on investment decisions based on an asset's grid location and the social acceptance of power not being equally valuable considering time and grid location. Furthermore, the increasing relevance of distribution grids through the high number of DERs and sector-coupling would result in the application of such concepts all the way to lower voltage levels, compared to existing approaches, which focus on the TS. Practical TS implementations of that can be found in different regions in the USA [15]. Considering the technical, computational and regulatory overhead of such an approach on the TS and also DS, it would result in a large effort. Either way, the potential solutions to this large-scale approach can range from nodal pricing concepts, all the way to self-managing grids through novel technologies like distributed ledger [16]. The general idea aims at combining grid and market. There would have to be incentives to adjust the behaviour of power system participants and transform all entities into active actors. This novel structure would aim at a system that allows for moving loads according to the RES feed-in into cheaper timeslots while also only allowing operation in the grids transmission capacities and having a transparent and secure overhead. The teased trend is summarized in literature by Transactive Energy Systems and shows a potential long-term solution for the operation of power systems [17].

# 3 TECHNICAL ASSESSMENT

The relevance of flexibility for future grid operation has been stressed in the previous sections. While the market coordination presents a central challenge, it only serves as the regulatory framework for actually changing the setpoint of assets according to the system's needs. Looking at flexibility solely from the technical perspective, various additional aspects have to be addressed and examined. In comparison to the market perspective with a lot of research potential on regulations and business cases, the research on flexibility from the technical side is currently further ahead. These applications target an (n-1)-secure system state and range from preventive tools for congestion prevention before operation to curative tools to react once congestion occurs. Some of these research topics include the determination of available flexibility at the grid connection point (GCP) to upstream voltage levels, probabilistic forecasting of available flexibility, dynamic controller structures for adjusting the power flow at a GCP, reduction of necessary grid expansion through flexibility utilisation, and a system monitoring with optimization and decision making for the DSO [13].

The continuation of these approaches will be carried out by new monitoring, protection, and control strategies, by market frameworks and by extending ICT infrastructures. This is especially relevant for ancillary services, which will partly rely on DERs in the future. During the real time operation of a flexible system, certain components are required for a proper execution. Especially the system monitoring in LV and MV distribution grids lacks the required technical infrastructure, though this may vary between different European countries and their rollout of necessary technical devices like Smart Meters. Either way, the DSO needs a sufficient state estimation and measurements to monitor the grid, which can also detect incoherent and anomalous events. Furthermore, the verification of flexibility activation has to be ensured as well. These components have to be integrated into the DSO's infrastructure with appropriate communication methods, though further communication channels for FOs like aggregators, the SO's coordination and the general exchange with novel flexibility platforms have to be implemented as well. This newly developed ICT system also has to ensure a sufficient cyber-security, since its easy customer access and large dimension could allow for cyber-attacks to a critical infrastructure, like power systems. An example for an upcoming risk is the possibility of intruders faking flexibility offers in an easily accessible market to cause problems or make profits. Further work on these topics is currently going on in the project in WP6 and WP7 [3].

The proposed schemes for flexibility markets in section 2 should allow for a sufficient reaction by the SOs in most situations, so that grid restrictions are not violated during operation. Though this is the aspired solution for congestion, situations will occur, when the network violations cannot be solved through the available options on the market or where unforeseen events cause critical network situations. In these situations, the SO has to be able to ensure a safe network operation by imposing control on the networks assets, whose feed-in may have already been contracted on the various markets. While this could affect a DS separately, it can also be a part of larger scale problems in the TS, which rely on subordinate DS adjusting their operation. An example can be seen in Germany, where the legislation prescribes a “cascading” down the voltage levels in case of pending emergency state, so that once a TSO cannot solve the problem on its own, the subordinate DSOs have to deliver their adjustment as part of the solution [18]. This state, in which the SOs have to take full control, has previously been mentioned for the traffic light model and is represented by the red phase. Since TS are equipped with advanced technological tools to react to these situations, the focus especially shifts to DSs, where the availability of such concepts and the technical implementation is only limited as of today. Therefore, a need for novel control and monitoring concepts exists.

The first part of that is the estimation of available flexibility potential within a grid, which is usually measured by what the grid can deliver at the GCP to upstream voltage levels. This is often visualized through PQ-diagrams, showing the current operating point and a region of feasible operating points at the GCP without causing network restrictions. This can also serve for general monitoring purposes by the DSO. Once a critical situation occurs, the DSO has to react and adjust its units according to the needs. If a certain power flow towards upstream grid is necessary, the PQ-diagram shows whether this operating point is feasible. Determining, which assets have to change their setpoint to deliver the targeted power flow at the GCP, while not causing network violations and doing this at minimal cost, is computed in the following step. The realization can be done through various approaches, like dynamic controllers, agent-based tools or through optimal power flows (OPF). As part of the project, an algorithm based on OPF’s is used to determine the feasible region in the PQ-diagram by overlaying it with a fine grid and testing the feasibility of each field in this checkerboard [19]. If afterwards a certain operating point is required and is deemed feasible, the OPF has previously already determined the optimal unit commitment in the grid and includes technical and economic conditions. Once again it has to be clarified tough, that it only serves emergency situations. Even if the TSO requests a certain power flow at the GCP, it is aspired to do this through the flexibility market, if the offered flexibility allows for it.

# 4 SYSTEM ARCHITECTURE

## 4.1 Format and role definitions

The HONOR deliverable 3.2 aims at creating a system architecture that combines all of the projects' modules and ideas into a holistic presentation. The main inputs used for the creation were delivered by user stories from different project partners stating their respective expectations and targets in HONOR, the resulting use cases and by oral exchanges in meetings. Since HONOR aims at developing a holistic system with a regional to interregional flexibility market, flexibility for ancillary services, monitoring of the cyber-physical system state and ensuring cyber-security, an appropriate approach for combining all contents is required. Based on the general discussion on grid and market in the previous chapter, the basic architecture defined in the SGAM was chosen as a reference. The SGAM is a unified framework for describing the system architecture of smart grids and therefore fits with the targeted system in HONOR. It is visualized in Figure 3 and consists of five layers, which describe the system in different dimensions while consisting of different domains and zones. As part of D3.2, the component, business and function layer are created, while communication procedures will follow in D3.3 and further technical specifications through the information and communication layer in D3.4.

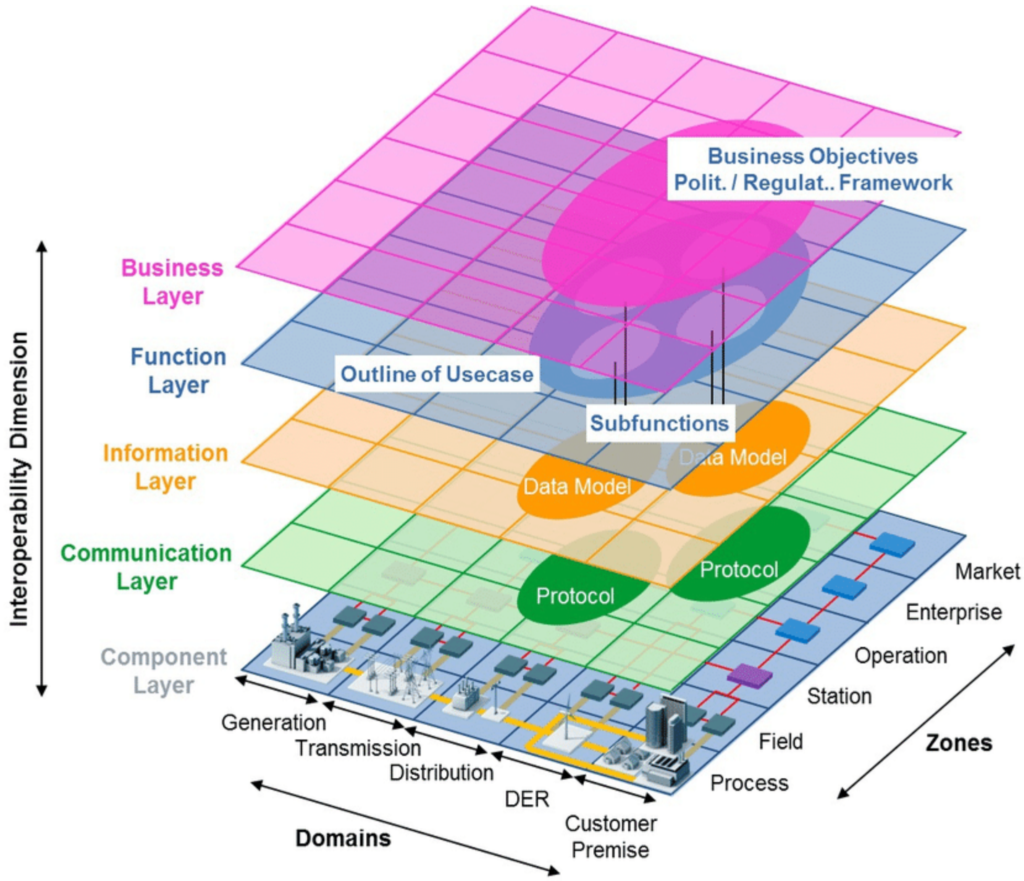


Figure 3: SGAM (Smart Grid Architecture Model)

It has to be mentioned, that the resulting plots and descriptions try to address the project's targets on a high level, because of the challenging task of a unified architecture with strong interdependencies between the projects' components like regulatory structures, market concept, and technical possibilities. An additional point is the applicability for different European countries and their highly varying present structures, depending on the political priorities, grid structure, market system, availability of technical components, regulations for technical components, and current trends for a future energy system. HONOR aims at combining all of these aspects into a feasible solution for all scenarios.

In order to elaborate the implemented concept and the various architecture layers, the roles within the system have to be defined. The definitions are limited to the necessary aspects in HONOR, so that the different roles could have expanded functions in other parts of the European energy system like potential interactions in international markets. This also applies to further specifications made in this document.

**MO:** The Market Operator (MO) is defined as the role, that hosts the market platform and ensures its operation. Depending on the market design, this role can partly be allocated to the DSO or TSO as they are the only buyer on this platform. For the purpose of this architecture, a separate entity is considered, as this leaves room for different market designs. Alongside this, the market will most likely be hosted on the ICT system of existing exchanges and therefore require the definition of a separate MO. Whether this MO performs actual matchings or whether the TSO/DSO does that, has to be specified in WP4.

**TSO:** The TSO manages the HV grid and requires flexibility at the GCP to the MV grid in case of congestion in the HV grid. This can be done through a request to the DSO who then gets active on the local flexibility market or via direct interaction on the local market by the TSO, depending on the market design. A close coordination with different DSOs is required either way.

**DSO**: The DSO manages the MV/LV grid and therefore owns the infrastructure, which the flexibilities in the context of HONOR are physically connected to. A constant system monitoring is required to coordinate the dimension and capability of the flexibility use. The market is used to purchase flexibility to prevent congestion in the DS or in case of a TSO request, in the TS. If the market is not allowing for a sufficient congestion management or if an imminent risk for violation of network restrictions is given, the DSO has to ensure the flexibility dispatch. Appropriate control algorithms have to be in place for such situations. The internal infrastructure of the DSO has to allow for performing all the stated tasks in a secure and reliable way.

**FO**: The FO provides flexibility for the SO on the market and performs the control actions as well. The role can be occupied by the **aggregator**, who manages a pool of flexibilities, and combines them into sellable products, or the **owner of a large flexibilities**, who markets and controls their flexibility themselves. In case of an aggregator, the flexibility deaggregation has to be performed, if pooled products are sold. The FO can either be a

BRP themselves and ensure a balanced BG through an internal coordination, or otherwise be contracted to a BRP (or BRP service provider) as all grid assets have to be balanced. That way the balancing task gets transferred to the BRP, while the BRP has to allow the FO to trade flexibility on the local platform.

**BRP**: The BRP is the responsible party for the balance in a BG and is affected by flexibility markets, since the FO trades cause imbalances. The BRP has to balance these imbalances in the context of HONOR. This can be done through trading on central markets or internal mechanisms (for example by larger BRP providers) in order to avoid imbalance payments. The BRP has to allow the connected FO to trade flexibility. The practical implementation can either be done by BRP trading on the spot market after the flexibility market [4] or by having internal compensation schemes from BRP providers [20].

**VSP**: The Verification Service Provider (VSP) is a newly defined role for performing the verification of flexibility transactions. The proposed flexibility market scheme results in a complex verification process where the physical delivery of contracted flexibilities has to be ensured. Since the existing parties in the context of the flexibility market have limited data availability, which has to be held up because of the competitive nature of a market, the verification process is decoupled from them and ascribed to the VSP. After the physical delivery is concluded, the VSP has to have a sufficient knowledge aside from the contract agreement to verify it. While for some assets a separate measurement is performed and can be used, others do not have one because of limited availability of measurement equipment. Also these assets could just be participating on the market in a larger aggregator pool. Depending on the sold flexibility service a scheduled baseline for single units may have to be available for a sufficient verification by the VSP. Otherwise the aggregator could potentially also just ensure matching an overlying target of the entire pool, that can be verified through measurements in the grid.

**ISR**: The imbalance settlement responsible (ISR) coordinates the processing after the physical delivery by checking contract fulfilments and billing the dispatched flexibility according to the VSP's verification.

**Meter Operator**: Operates the distributed meters in the power system and provides the data to the DSO, the aggregator and the VSP. Can also be in the hand of the DSO, depending on a country's regulations, but is modelled separately in the context of HONOR.

## 4.2 SGAM Layers

### 4.2.1 Component Layer

In reference to the bottom-up approach of the official SGAM documentation [1], the creation starts with the component layer in Figure 4, which includes the physical distribution of all participating components. Here, the components are connected conceptually, while D3.4 will deliver more details about the communication infrastructure and the protocols.

The process and field zones show the power system and its connection to the SO and the flexible assets and their respective controller and smart meter. The assets are divided between large assets, which are equipped with a connection to the DSO according to the regulations, and small assets, where the controller is only connected to the aggregator. The smart meters are part of an advanced metering infrastructure (AMI) and connected to the meter operator, which forwards the data to the DSOs, the aggregators and the VSP. Within the DSOs infrastructure, a number of common components are included as well, like a head-end system (HES) for the connection the components in the field and process layer, a human machine interface (HMI) and a distribution management system (DMS). A gateway establishes the connection to external devices towards the market and the TSO. The aggregator and the owner of a large flexible asset are connected to the market as the FO offering flexibility. Both are also connected to the BRP as their contracts have to allow for flexibility trading and the resulting data exchange. The VSP collects data from the DSO, aggregator, and meter operator and forwards the verification to the ISR. The ISR settles the BRP's position post processing. The BRP is contracted with the TSO.

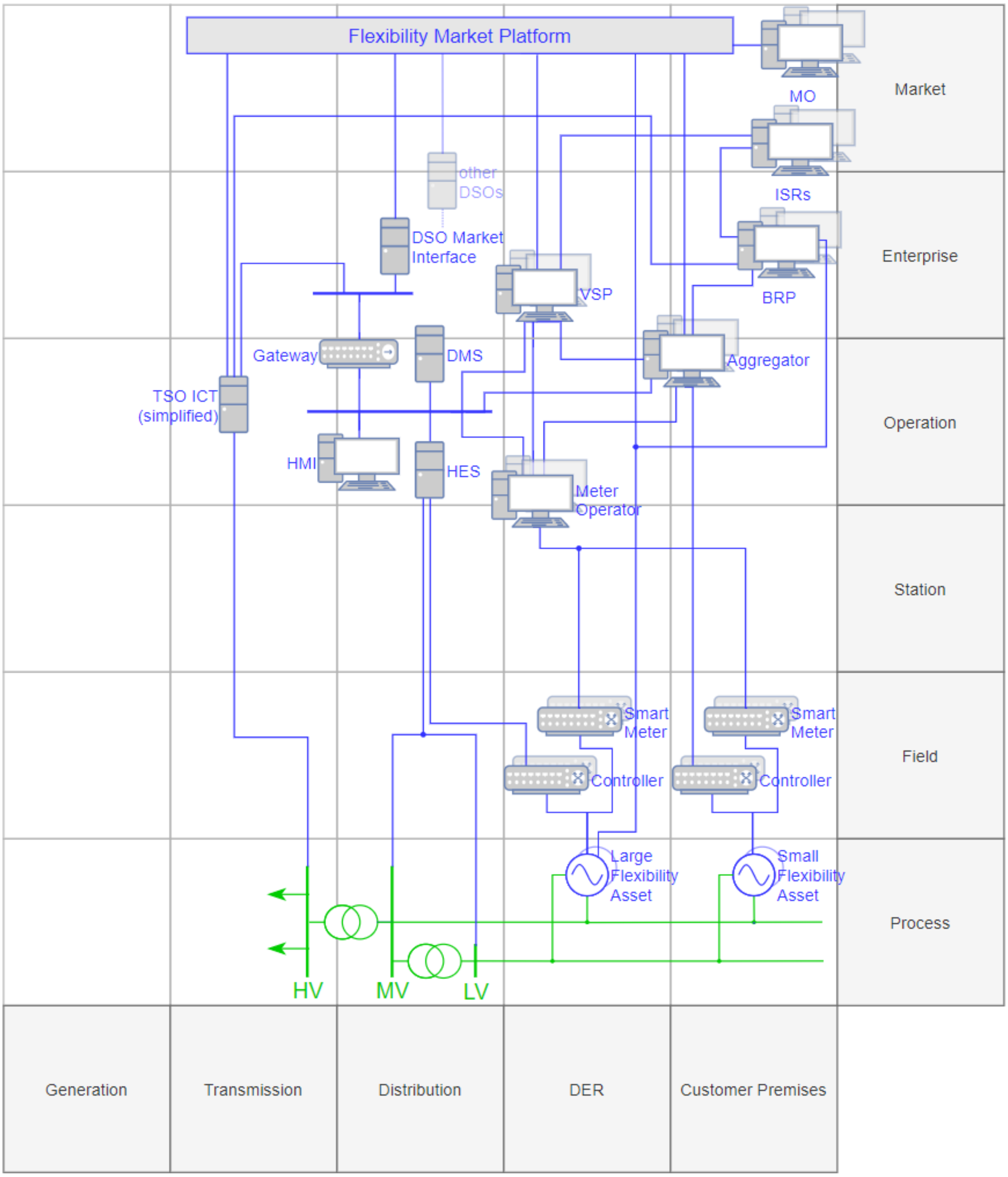


Figure 4: Component Layer

### 4.2.2 Business Layer

The business layer in Figure 5 now further elaborates the relation between participating parties and is partly based on [21]. The owner of the small flexible assets fully transfers the marketing and control of his flexibility to the aggregator, who therefore occupies the role of the FO. By doing this, the owner has the ability to include his flexibility into a pool of assets, which can be sold on platforms in order to make a profit for the owner, while the aggregator collects his share of the revenue as well. The exact definition for the aggregator depends on the market design and the integration into the general market system, as a participation in other markets, like it is done through a virtual power plant today, could be possible as well. The owner of a large flexible asset markets the flexibility themselves and the activation can be done internally, or by the DSO in case of large DER units with an existing communication, depending on the asset type. Both types of FO are contracted to a BRP, who is contracted with the TSO through the BG in the control area, and the FO flexibility trading causes imbalances for the BRP. In HONOR this is dealt by committing the BRP to balance the imbalances caused by the FOs on the intraday market or through internal mechanisms [4].

The meter operator collects measurements from the flexibility owners and provides the data to the aggregator, the DSO, and the VSP. Depending on a country's regulations, the metering can be part of the DSO. The DSO co-manages the market platform and purchases flexibility, if necessary, or closes the market to impose control in critical situations. The coordination between TSO and DSO is an important part of the local flexibility market. While this depends on the market design, some core components of that connection can be specified. Local markets aim at congestion management, which will primarily be relevant in the TS, though the units are positioned in the DS. A flexibility demand by the TSO has to be feasible within the grid capacities of the DS. Therefore, this demand has to be realized through a market interaction by the DSO, based on the TSOs incentives. Thus, a close coordination between DSO and TSO is required for the efficient operation of the flexibility markets.

The VSP has to ensure that the contracted flexibility is physically delivered. Therefore, the market results have to be made available to the VSP by the MO. Furthermore, the VSP uses meter data and additional asset data from the aggregator and DSO (asset location, asset type, BRP contracting) to verify the market transactions. The VSP forwards that to the ISR, who performs the monetised settlement and ascribes the results to the BRP. If a FO does not deliver the contracted flexibility, the VSP detects this and initiates the handling according to the market framework, which could result in penalty payments, a reduction of the reliability score or a temporal exclusion from market transactions for the FO.

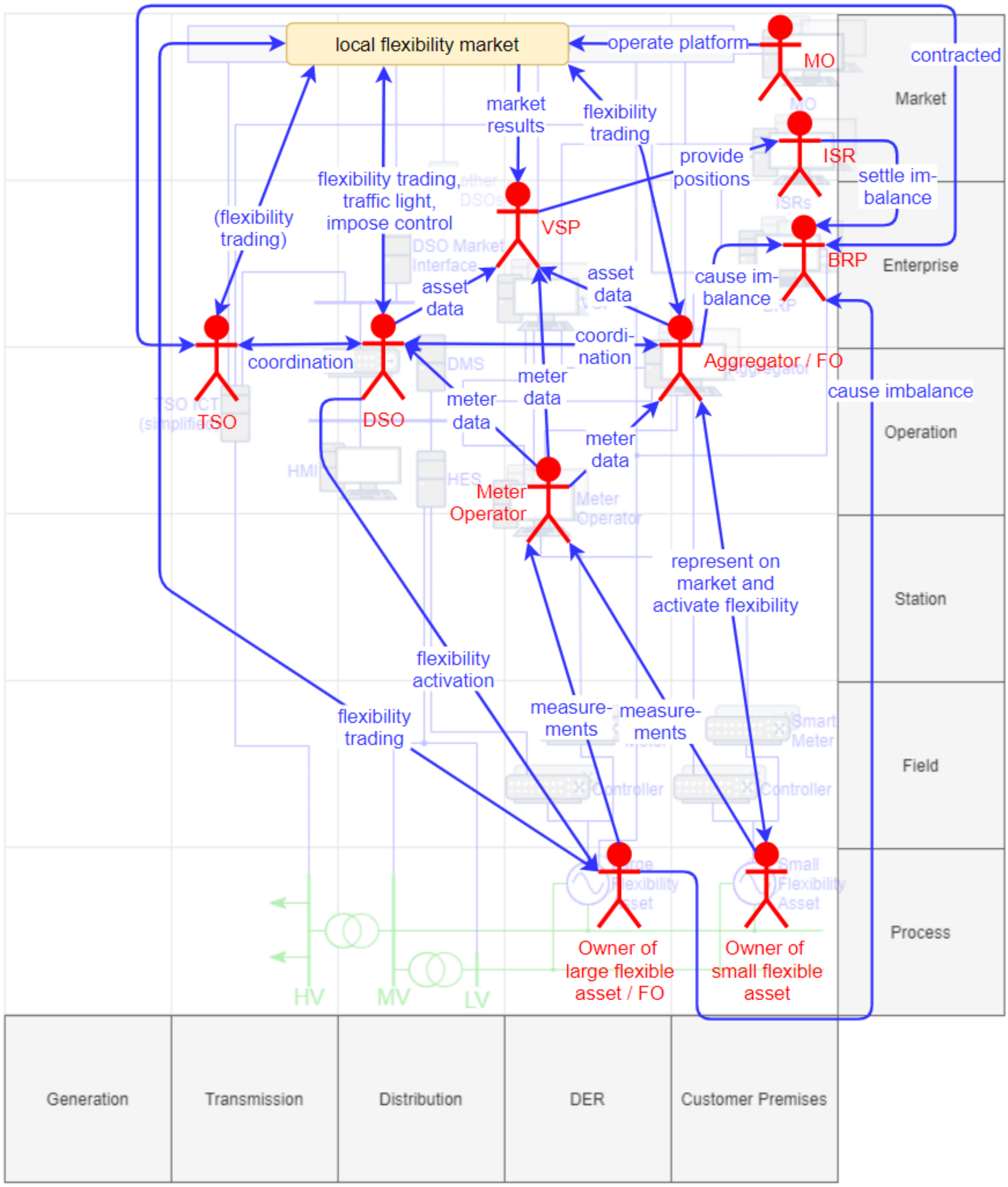


Figure 5: Business Layer

### 4.2.3 Function Layer

The function layer now extends the previously mentioned relations and role definitions by formulating the core functions. The layer is visualized in Figure 6 and hosts the respective functions, whereas the connection lines emphasize on the basic relation, which were more extensively described in the business layer. The flexible assets provide the flexibility, whereas the controller allows for a setpoint adjustment and the smart meter forwards measurements. The meter operator collects and forwards the measurements, which also includes the operation of a reliable AMI.

The function of a FO is to offer flexibility. This includes the process to predict available flexibility, create the monetary assessment, and position these to the demands of the DSO on the market platform. Depending on the matching of previously positioned offers, the FO may adapt its pricing. The corresponding BRP gets notified by the FO and has to react to the imbalances via internal measures, trading on central platforms or other balancing mechanisms. After the physical delivery is completed, the VSP has to verify the positions with the information according to the business layer. The verification process results in a quantification of the imbalances, which the ISR uses to settle the positions for the BRPs. If the FO does not deliver the flexibility, further measures according to the regulatory structure are initiated based on the VSP's verification.

As the DSO emphasizes a central role within this system architecture with many functions, this layer only covers the central functions for the flexibility market framework in HONOR. The relation to the grid covers performing control actions and the general data processing of measurements within the grid. The DSO constantly has to monitor the grid regarding a safe operation, though this function also covers the system state estimation and using forecasts to predict the system state in future scenarios. Based on the results, an estimation of the flexibility demand has to performed, where a pending congestion is transferred to a flexibility demand for the market. If the monitoring detects a grid utilisation, where the market does not allow for a sufficient solution, the DSO has to calculate the optimal flexibility dispatch for the red phase of the traffic light. In either scenario, the DSO's HMI hosts the decision making, where the reactions and the behaviour of the DSO regarding all the surroundings is coordinated.

The MO operates the market platform, which serves as the hub to forward the flexibility trades between all participants. The MO also performs the matching of flexibility demand and what the FOs provide, though this task may be occupied by the DSO/TSO, depending on the market design. The market coordination of the DSO covers the determination of the traffic light status based on the system monitoring and the positioning of the flexibility demand. While the TSO's role depends on the market design as well, it either way covers the determination of required flexibility to relieve congestion in the TS and the positioning of offers towards the DSO or on the market platform.

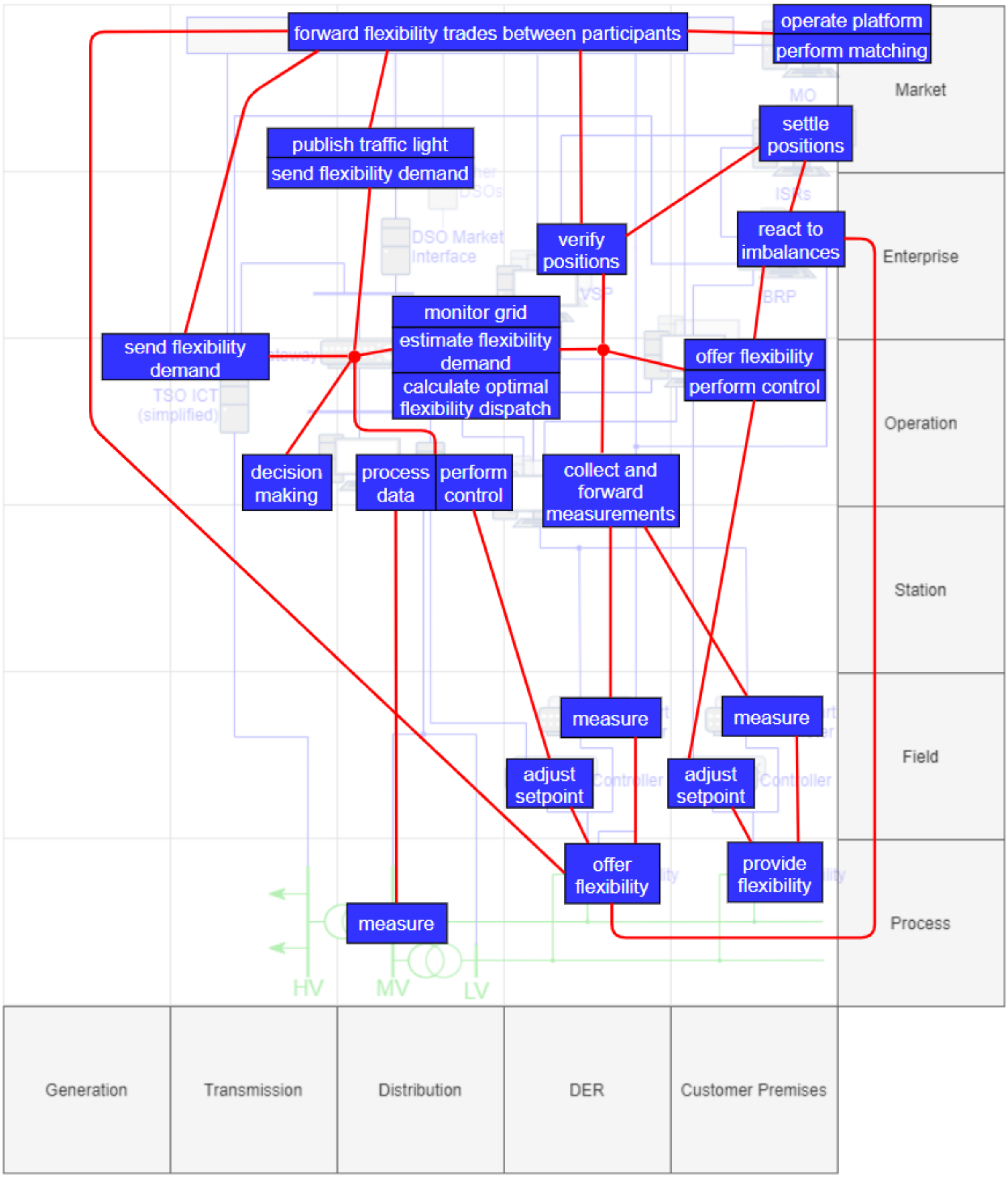


Figure 6: Function Layer

## 4.3 Data streams

| # | Name | From | To |
|---|---|---|---|
| 1 | DS grid measurement signals | Measuring device in DS | HES |
| 2 | Grid measurements | HES | DMS |
| 3 | Meter data from assets | Smart Meter of large and small flexible asset | Meter Operator (AMI) |
| 4 | Meter data for aggregator | Meter Operator (AMI) | Aggregator |
| 5 | Meter data for DSO | Meter Operator (AMI) | DMS |
| 6 | Setpoint adjustment from aggregator to small flexible asset | Aggregator | Controller of small flexible asset |
| 7 | Setpoint adjustment from DSO to large flexible asset | HES | Controller of large flexible asset |
| 8 | System-state monitoring and prognosis | DMS | HMI |
| 9 | Control decisions | HMI | HES |
| 10 | Decisions on market actions | HMI | DSO Market Interface |
| 11 | Market coordination (bidirectional) | HMI | TSO ICT |
| 12 | HV grid measurement signals | Measuring device in TS | TSO ICT |
| 13 | Flexibility demand (depending on market design) | TSO ICT | Market Platform / MO |
| 14 | Flexibility demand or restrictions | DSO Market Interface | Market Platform / MO |
| 15 | Flexibility Offer | FO (aggregator or owner of large flexible asset) | Market Platform / MO |
| 17 | Market results based on positioned demand | Market Platform / MO | DSO Market Interface |
| 18 | Setpoint adjustments in the grid after market clearing | DSO Market Interface | DMS |
| 19 | Market results based on positioned demand | Market Platform / MO | TSO ICT |

| | | | |
|---|---|---|---|
| 20 | Market results for placed offers | Market Platform / MO | FO (aggregator or owner of large flexible asset) |
| 21 | Market results for affected units | FO (aggregator or owner of large flexible asset) | BRP |
| 22 | Meter data after flexibility dispatch | Meter Operator (AMI) | VSP |
| 23 | Market Results | MO | VSP |
| 24 | Asset Data (unit type, location, BRP relation) | Aggregator | VSP |
| 25 | Asset Data (unit type, location, BRP relation) | DSO | VSP |
| 26 | Verification of contracted flexibility | VSP | ISR |
| 27 | Imbalance settlement | ISR | BRP |

# 5 CONCLUSION AND OUTLOOK

D3.2 delivers a description of the structural organisation of the different topics in HONOR. The complexity of the interdisciplinary topic is broken down by a general discussion on flexibility markets and their corresponding framework. The requirements and challenges for the project are discussed with the possible realization approaches. The implementation is partly dependent on subsequent work in other WPs and therefore leaves certain topics unclarified, but delivers a solution for the most aspects with overlapping relevance for different WPs. Furthermore D3.2 creates the system architecture with the component, business, and function layer as a high-level overview for the research in HONOR. It visualizes the core roles and their technical connections and business relations.

Further work in WP3 will continue with the communication sequences and the communication and information SGAM layers. WP4 will provide the full market framework including more insights on the TSO-DSO coordination in D4.1 [22]. WP5 will deliver the control algorithms and WP6 and WP7 will elaborate much further on the technical side of the HONOR architecture through a separate technical architecture in D6.1 [3].

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