A SGAM-Based Architecture for Synchrophasor Applications Facilitating TSO/DSO Interactions

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***Abstract*— Distribution grid dynamics are becoming increasingly complex due to the transition of these networks from passive to active networks. This transition requires increasing the observability and awareness of the interactions between Transmission and Distribution (T&D) grids, particularly to guarantee adequate operational security. As part of the work carried out in the EU-funded IDE4L project, a specific use case, containing PMU-based monitoring functions, has been defined to support the architecture design of a distribution grid automation system. As a result, the architecture can accommodate for synchrophasor applications that provide key dynamic information extraction and exchange between DSO and TSO. This paper presents the use case and the portion of the IDE4L architecture that accommodates for scenarios that exploit synchrophasors for monitoring applications.**

***Index Terms*—active distribution grid, architecture, PMU, SGAM, WAMS.**

I. INTRODUCTION

To facilitate adequate technical functioning of the overall electric power system, the interactions between the technical operation of distribution grids and the main transmission grid requires to "exchange information" that can help in the technical functions of both network operators. As of today, it is challenging for Distribution System Operators (DSOs) to provide and maintain a network model of their electrical grid, which if constantly updated, could help in extracting key information about the network's state. In addition, DSOs currently do not have access to nor exchange much measurement data with the Transmission System Operator (TSO), and if they do, very little (or non) of these measurements are shared in hard real-time, nor do they have high sampling resolution and time-synchronization. This means that the measurement data available is too limited in quantity (i.e. locations and signals), and also in "observability" (i.e. the content of the frequency spectrum from their sampling resolution) [1].

Therefore, in the current situation, a short-term solution to enhance "information exchange" would be to make available new measurement devices that provide real-time, high-sampled data across operational boundaries from which information can be extracted. To this end, the work within the *Ideal Grid For All* (IDE4L) project, funded by the European Commission, considered the utilization of time-synchronized phasor measurements with millisecond reporting rate, i.e. real-time data from Phasor Measurement Units (PMU) [2]. This approach is sensible considering the recent trends in North America and Europe to explore the potential of utilizing PMUs at the distribution level [3,4]. The implementation of such PMU-based "information exchange" has to go through a properly designed and implemented architecture that can satisfy all application-dependent technical requirements, while at the same time considering the different actors and operational boundaries involved.

The IDE4L architecture is built upon the 5-layer Smart Grid Architecture Model (SGAM) framework that has been developed by the CEN-CENELEC-ETSI Smart Grid Coordination Group [5]. The SGAM is the main response to the EU Mandate M/490 for the development of a framework to support European smart grid deployment [6]. The main inputs to the architecture design are the use cases that describe the architecture requirements, actors and functionalities. The use of SGAM aids in developing a common understanding between power grid domain experts and IT experts [7]. The IDE4L architecture is built from several use cases, one of which is the "Distribution grid dynamic monitoring" defining PMU-based monitoring functions that can provide key dynamic information for both the Distribution Management System (DMS) of DSOs and the Energy Management System (EMS) of TSOs.

This paper presents the "Distribution grid dynamic monitoring" use case and its mapping on the SGAM framework. This mapping gives the portion of the IDE4L architecture that can accommodate for the scenarios that exploit synchrophasor technology for monitoring applications. The paper begins by presenting the use case in Section II. Sections III illustrates the use case mapping on different layers of the SGAM framework. Conclusions are drawn in Section IV.

II. USE CASE DEFINITION

As indicated in the previous section, the objective of the "Distribution grid dynamic monitoring" use case is to manage the complexity and increased inter-dependence between electric power transmission and distribution grids, that have

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raised as a result of the ‘energy transition’. The “business case” considered herein is to support a long-term sustainable energy system. One strategy to achieve this is through exchange of key dynamic information between TSOs and DSOs. Key information extraction and exchange will be performed by coupling PMU data from different voltage levels across the operational boundaries of the grids, and exploiting it coherently in PMU applications that derive actionable information.

Figure 1 illustrates the use case diagram, mapped on the *Smart Grid Plane*. The *Smart Grid Plane* spans in horizontal dimension the complete electrical energy conversion chain, partitioned into five domains of Generation, Transmission, Distribution, DER and Customer Premises. In the vertical dimension, it spans the hierarchical levels of power system management, partitioned into six zones of Process, Field, Station, Operation, Enterprise (not shown) and Market (not shown). The plane enables the representation of the zones in which power system management interactions between domains or inside a single domain take place. More information on the domains and zones can be found in [5].

As shown in the figure, synchrophasors are provided by PMUs distributed on the feeders, installed at the Primary Substation (PS) or at the Secondary Substation (SS). The synchrophasors are then collected by the PS-level and the SS-level Phasor Data Concentrators (PDC) which, in turn, stream the data through a Wide Area Network (WAN). The data is transferred either over TCP/IP on IEEE C37.118.2 protocol or over UDP/IP on IEC 61850-90-5 protocol to a higher level in the architecture hierarchy. The data is finally delivered to DMS computers at the DSO for real-time processing and extraction of dynamic information, performed by newly developed monitoring applications. The outputs of the applications are to be used by other DMS functions; however, some key dynamic information is selected to be sent to TSO to support the EMS functions.

As Figure 1 indicates, because some of the synchrophasor applications can be implemented in distributed fashion within the architecture, data processing and information derivation is performed at both the Station and the Operation zones.

The actors involved in this use case are transducer (i.e. instrumentation chain including CTs and VTs), PMU, PDC, communication interface, DMS, and EMS [8]. The functions involved in this use case are electrical conversion, synchrophasor calculation, data acquisition, data concentration and time-alignment, data exporting, data curation, extraction of different time-scale components from the PMU data, and derivation of key information out of the data. Note that the functions run regularly, i.e. no triggering event is considered in this use case. As mentioned before, once the use case description is available, it is possible to realize the use case mapping onto the SGAM layers.

III. THE SGAM ARCHITECTURE

As mentioned previously, the IDE4L architecture is constructed based on the SGAM reference model to analyze and visualize the use cases in a technology-neutral manner.

Figure 2 depicts the three-dimension representation of the SGAM framework which is established by merging the concept of the interoperability layers with the *Smart Grid Plane*. As the figure shows, the SGAM consists of five interoperability layers representing business objectives and processes, functions, information exchange and models, communication protocols, and components. Note that in addition to the relations between objects on the same layer (e.g. physical connection of components on the component layer), there exist interrelations between objects on different layers. Business processes, as objects of the business layer, are realized by functions, as objects of the function layer, which are in turn executed by components, as objects of the component layer. The execution of the functions requires the components to support data models, as objects of the information layer, and communication protocols, as objects of the communication layer. More information on the layers can be found in [5].

This section shows the mapping of the “Distribution grid dynamic monitoring” use case, defined in Section II, on the SGAM layers. This mapping gives the portion of the IDE4L architecture that can accommodate for the scenarios that exploit synchrophasor technology for monitoring applications.

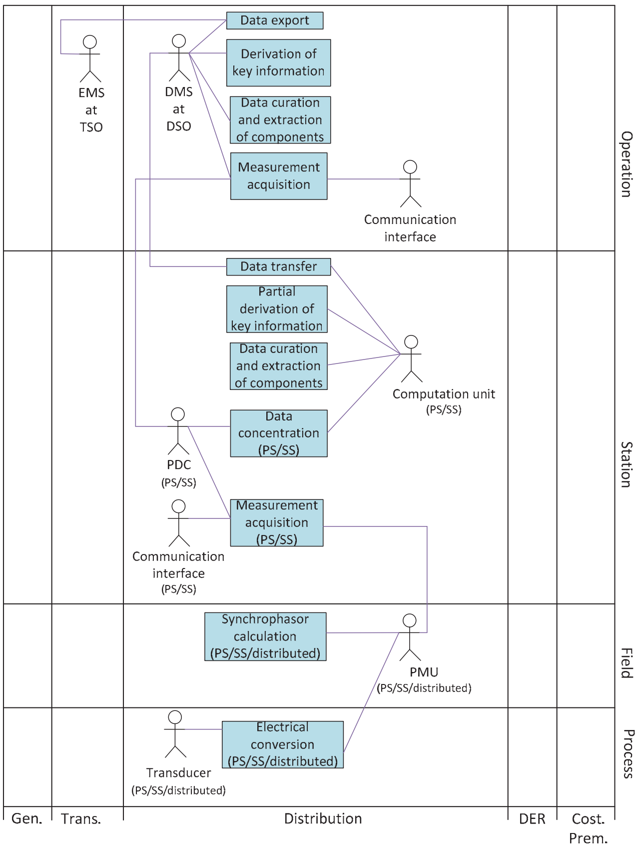

Figure 1. Diagram of the “grid dynamic monitoring” use case mapped on the *Smart Grid Plane*.

A. Development of the Component Layer

The component layer depicts the use case actors in form of hardware which is used to provide the intended use case functionalities. As shown in Figure 3, the computers at the Station and the Operation zones host the PMU-based monitoring functions. The computers are fed by the PMUs at the Field zone through the PDCs at the Station zone. In addition, the Modem+Switch components represent the connection between the Local Area Networks (LAN) and WANs. Note that the component layer is beneficial on evaluating the cost of the components that are to be utilized in the architecture.

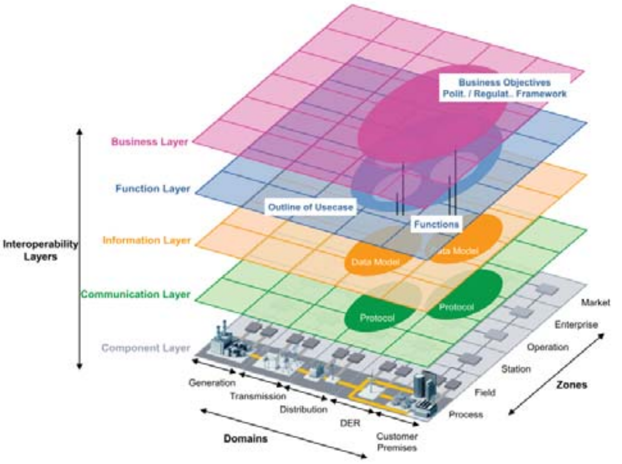

Figure 2. The Smart Grid Architecture Model (SGAM) framework [5].

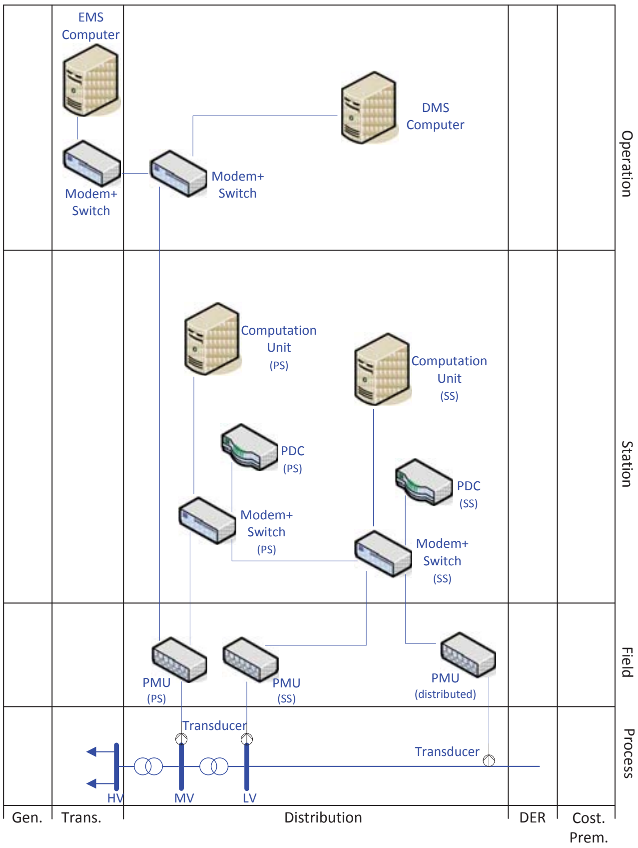

Figure 3. The use case mapped on the SGAM component layer.

B. *Development of the Business Layer*

The business layer is intended to host the business processes, services and organizations, the business objectives, economic, and regulatory constraints underlying the use case. However, it is suggested in [7] to move apart the business aspects of the use case to be documented in a separate use case definition. This is because a technical use case might be exploited to achieve multiple business objectives, i.e. there's no one-to-one mapping between the technical use cases and the business objectives. Although the IDE4L project has adopted the same viewport, the business layer is derived in Figure 4 for the sake of illustration. As depicted in the figure, the business layer shows the area which is affected by the use case and consequently influenced by its underlying business objective.

Figure 4. The use case mapped on the SGAM business layer.

C. *Development of the Function Layer*

The function layer is intended to represent the functions, realizing the use case, and their interrelations with respect to domains and zones. The position of the functions is inferred from the use case diagram mapped to the *Smart Grid Plane*, shown in Figure 1. The interrelations can be derived from the list of exchanged information that will be further explained in the next section. In addition, the function layer provides a function-to-component mapping which in turn helps in the definition of software and hardware requirements of the components.

Figure 5 shows the use case mapped on the SGAM function layer. The main functions, developed during the IDE4L project, are briefly explained below. The readers are referred to the provided references for further details.

- *Data Curation and Extraction of Components:* This function is based on an enhanced Kalman Filtering technique that performs both bad data removal (i.e. eliminating noise, outliers, and missing data) and signal feature extraction (e.g. steady state components, dynamic components with different time scales, etc.) from the PMU measurements in real-time. Hence, both input and output of this function are synchrophasors [8,9].
- *Derivation of Key Information:* This is actually a family of functions including *Steady State Model Synthesizer* [9], *Oscillatory Mode Meter* [10], *Voltage Stability Analyzer* [11], *Sub-synchronous Oscillation Detector* [12], and *Feeder Dynamic Rating* [13]. The inputs to all of these functions are *curated* voltage and current synchrophasors whereas their outputs consist of different number sets in floating point format, often having lower reporting rate compared to that of the synchrophasors.

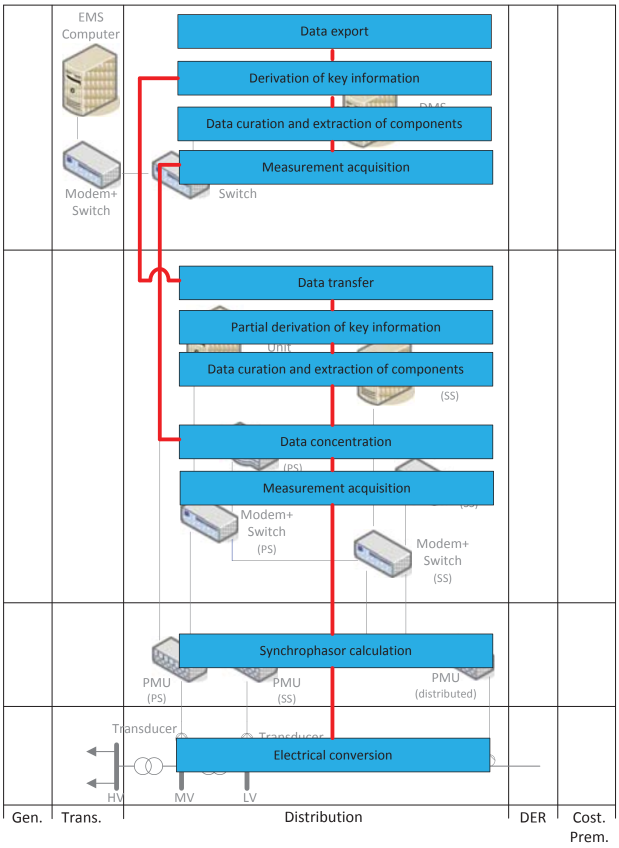

Figure 5. The use case mapped on the SGAM function layer.

D. Development of the Information Layer

The information layer is depicted in two views of *Business Context* and *Canonical Data Model*, where the former one describes the information being exchanged between the components and the latter one is intended to show underlying canonical data model standards which are able to provide information objects needed for the implementation of the use case. Specification of the data model standards helps in the selection of the proper software to be installed on the components of the architecture.

Figure 6 shows the use case mapped on the SGAM information layer. Note that the two views of *Business Context* and *Canonical Data Model* are usually shown in two separate figures; however, due to the space limitations, they are merged into one figure in this paper. The exchanged information, shown in the figure, is consistent with the specification of the inputs/outputs of the functions, explained in the previous section. In addition, as the figure indicates, IEC 61850-7-4 is used for the data modeling of the PMU measurements that are mapped to the logical node *MMXU* data objects of the IEC 61850 standard [14]. This is consistent with the communication protocol, used to transfer the synchrophasors, which will be further discussed in the next section.

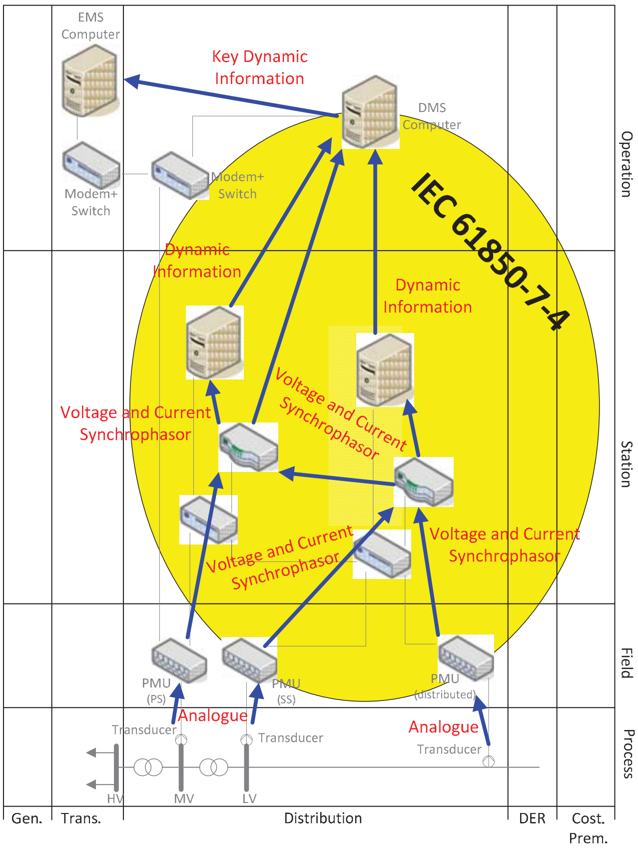

Figure 6. The use case mapped on the SGAM information layer.

E. Development of the Communication Layer

The emphasis of the communication layer is to describe communication protocols and technologies for the interoperable exchange of information between the components. In addition, the layer can be used for cost assessment in the construction and the management of the required communication infrastructure. Figure 7 shows the use case mapped on the SGAM communication layer. As the figure shows, while the synchrophasors are transmitted on IEC 61850-90-5 protocol, the derived dynamic information are communicated on an arbitrary Web Service which can be any protocol using the TCP/IP or UDP/IP client-server mechanism. It is worth noting that a gateway has been developed in the IDE4L project to transmit the PMU data on IEC 61850-90-5 protocol [14,15]. The gateway allows to transfer the PMU data by mapping and encapsulating the synchrophasors (that are already mapped to the *MMXU* data objects) in GOOSE or Sampled Value messages and sending them over UDP/IP. The gateway sits at the server side (i.e. PMU or PDC) to generate IEC 61850-90-5 messages and at the client side (i.e. PDC or computation unit) to parse IEC 61850-90-5 messages, acting as a data mediator for user applications.

As mentioned before, another aspect of the communication layer is to assign appropriate technologies for communication links between the components. Each information exchange sets specific requirements in terms of transfer time, transfer rate, synchronization accuracy, and availability on the communication link through which it's transmitted. Hence, proper technologies should be assigned to the links to satisfy the requirements imposed by the information exchanges. For instance, while fiber-optic communication is recommended for PDC-to-PDC and PDC-to-computer links (due to the high transfer rate and transfer time requirements), LTE and point-to-point HiperLAN technologies may also be used for PMU-to-PDC and computer-to-computer links (due to the lower requirement on transfer rate) [16]. Assuming that the information exchanges within the use case require a high level of communication link availability, it is important to consider some sort of redundancy by for example constructing communication infrastructure in parallel or utilizing other communication links to implement a parallel path.

IV. CONCLUSIONS

This paper presented a use case, containing PMU-based monitoring functions, and its mapping on different layers of the SGAM framework to support the architecture design of a distribution grid automation system; such that the architecture can accommodate for key dynamic information exchange between TSOs and DSOs. As future work, different metrics will be defined to evaluate the performance of the designed architecture.

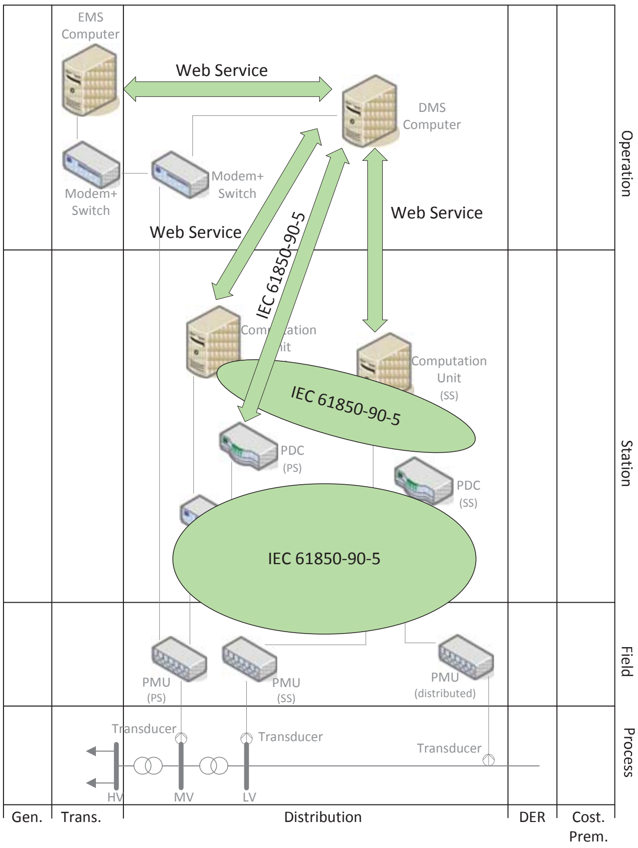

Figure 7. The use case mapped on the SGAM communication layer.

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