First experiences with customer specifications of IEC 61850 based Substation Automation Systems

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Abstract - *The standard IEC 61850 „Communication Networks and Systems in Substations" allows for interoperability between the intelligent electronic devices (IEDs) for protection, monitoring, control and automation in substations. Suppliers have implemented or are implementing this standard now. Utilities have to specify the IEC 61950 based SA systems such that both the customer requirements are met and the features of the standards are considered and its benefits are exploited. From the viewpoint of IEC 61850 the customer specification has to include three areas of requirements, i.e. the functionality needed, the performance requested, and all boundaries applicable.*

In the meantime, first experiences with customer specifications of IEC 61850 based SA systems have been collected. Depending on their knowledge about the standard and concerns about changes, utilities have a very different specification behavior. Some state only IEC 61850 for the communication system without details, others start a comprehensive discussion for nearly all details of the solution.

Keywords: Substation automation – SA – Specification - IEC 61850 - Data model – Services - Signal list – Tools - Substation configuration description language – SCL – Utilities

1   INTRODUCTION

More than 4000 Substation Automation (SA) Systems installed worldwide have proven the acceptance of substation automation systems and the appreciation of its benefits for the utilities [1]. Since there was no standard for the serial communication in SA, all these systems are using proprietary standards. This means that only components from one supplier are used or costly and limiting protocol conversions have to be applied. The first step towards standardization in SA was IEC 60870-5-103 [2] for the informative interface between SA and protection devices. To provide interoperability between the devices for all functions performed in substations, the standard IEC 61850 [3] was developed in the last ten years. The fourteen parts have been issued by IEC between 2003 and 2005. Important points are also the free allocation of functions and the future proof approach of this standard.

The benefits of this standard have been discussed in many events, especially of Cigre SC B5, and already stated in early papers like [4]. The increasing commitments of suppliers to use and offer this standard in products and systems was clearly demonstrated at the UCA International exhibition at the Cigre 2004 in Paris [5]. Ordering at least first pilot installations in late 2004 and continuing in 2005 raised the question what has to be specified for SA based on IEC 61850. Is there a difference to SA specifications before? A first paper was issued at the DistribuTech [6]. The WG11 of Cigre B5 [7] studying the introduction of IEC 61850 and its impact on utilities will issue its report soon. The first projects have provided a first experience how the utilities approach the problem of specification of SA based on IEC 61850 and what problems happen due to different understanding of the standard on utility and solution provider side. Important points of this first experience are discussed in this paper.

2   BASIC CONSIDERATIONS

2.1   The standard IEC 61850

The basic goals of the standard IEC 61850 [3] are to
- provide *interoperability* between devices of different manufacturers, i.e. also all functionalities beyond the pure informative interface
- support *free allocation of functions to devices*, i.e. it has to allow different system philosophies of the user like decentralized or centralized functions
- guarantee long term stability of the standard, i.e. it has to be *future proof* being able to follow the progress in communication technology as well as evolving new system requirements

The approach to reach these goals is the definition of domain specific *data model* with standardized objects and standardized services. Selecting mainstream communication means like Ethernet solves the third point. Supported is the goal by the substation configuration description language (SCL) standardized in IEC 61850 also.

2.2   The specification

The starting point for any specification is the switchyard in form of a single line diagram. This implies also the topography and the environment of the substation, the kind of switchgear, and the process interface to the SA system. The key point for SA system specification is the requested functionality depending on the needs of the substation and the operating philosophy of the utility. This implies also the interface to the network control system. This *functional specification* is the same as before the advent of IEC 61850 based substations.

What implementation details have to be specified depends on the philosophy of the utility. In the past, it was the complete wiring and marshalling, the cubicles with all the devices, and the operation panel. Already with the advent of intelligent electronic devices (IED) and the serial communication, data and communication replaced some of the previous hardwired schemes. A key point is the signal list.

What's different with IEC 61850? As shortly outlined in section 2.1, it is the object oriented data model, the flexibility of mainstream communication means (e.g. Ethernet), and the guarantee of interoperability between devices from all contributing manufacturers.

The specification may hold on functional level or being extended down to bits and bytes. An adequate hierarchical approach to specification including the reasons and impacts of all the different levels of details is given e.g. in [6].

2.3   The customers

In the working groups, also experts from some utilities have contributed to the standard, especially in defining the requirements. Before the standard was issued by IEC, most utilities got information from dedicated meetings and publications only. Another limitation is the number of experts in utilities and the more than 1000 pages of the standard. As indicated above in section 2.2 to specify an IEC 61850 based SA the full understanding of all details of the standard is not needed.

According to the hierarchical approach of specifications, the requirements and the know-how of the customer, different procedures for the specification process are experienced and acceptable, especially for the very first SA installations with the new standard IEC 61850. The functional part of the specification (single line diagram, requested functionality, on-site conditions) as discussed above in section 2.2 has to be provided in any case. For all the additional details, two extreme positions are possible and have been experienced:

2.3.1   Customers not defining any IEC61850 details

- General request for an IEC 61850 conformant system to all addressed suppliers. No additional coordination effort between customer and supplier during the project execution was requested e.g. same amount of meetings as for a SA systems with proprietary communication
- The complete responsibility was delegated to the supplier since there was trust in the competence of the supplier by the customer regarding the IEC 61850 modeling
- The focus was on factory acceptance test and site acceptance test
- The scope of the project was one substation to get refurbished bay-wise

2.3.2 Customers defining extensive IEC61850 details

- The customer requested to get heavily involved in the IEC 61850 modeling of the SA system for influencing it according to his intended utility standard. As IEC 61850 was very new for the customer he used the project also to get more know-how on the IEC61850 standard.
- The customer has not delegated many responsibilities concerning the implementation of the IEC61850 for a SA system
- Therefore, many working group meetings have been performed with the customer and some pre-qualified suppliers to
  - learn about the standard IEC 61850
  - to bring in a lot of detailed requirements
  - get convinced about any detail of interoperability according to IEC 61850
- The scope of the project was to start after comprehensive tests a retrofit of a lot of substations over the coming years

3 ISSUES FROM THE SPECIFICATION (PROCESS)

3.1 General remarks about issues and solutions

The issues raised by the first specifications and the applied solutions represent both the actual status of the standard IEC 61850 as issued by IEC between 2003 and 2005 as international standard (IS) and the introduction phase. Increasing know-how about the standard and experience with SA systems based on IEC 61850 and amendments of the standard may change the situation in the future. Nevertheless, the experience with first specifications looks very typical and should be used for clarification between utilities and suppliers improving and facilitating the specification. Formal steps for specification in the context of IEC 61850 are possible. This paper leaves it open, if the translation from conventional to formal specification is made by the user, the provider or by a system integrator.

3.2 The data model

3.2.1 Signal List and Data Model
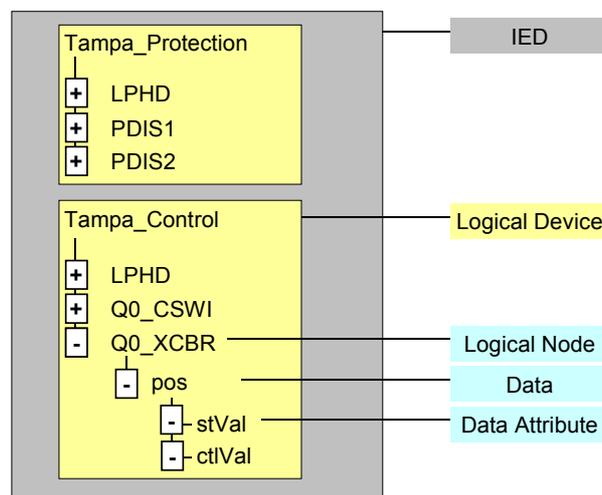
Figure 1 – Some details of the Data Model according IEC 61850 for Bay Protection and Control

<u>Issue:</u>

The signal list with all signals exchanged between source and sink was in many cases a key part of the specification of a substation automation system. Up to know it could be specified independently from the communication system used. In IEC 61850, the focus of specification is on the data model as defined for the source or sender side, i.e. the server in the client-server approach used. Not all utilities have noticed that there is

an important difference between the Data Model according to IEC 61850 and the Signal List used up to now in specifications.

Solution:

It has to be explained to the customer that signal list entries are mainly derived from the data model by defining data sets for the communication services used. Data model entries and signals from conventional signal lists can be compared in one table. For better understanding, the data model is outlined in and the relationship between data model and signal list is shown in Figure 2.
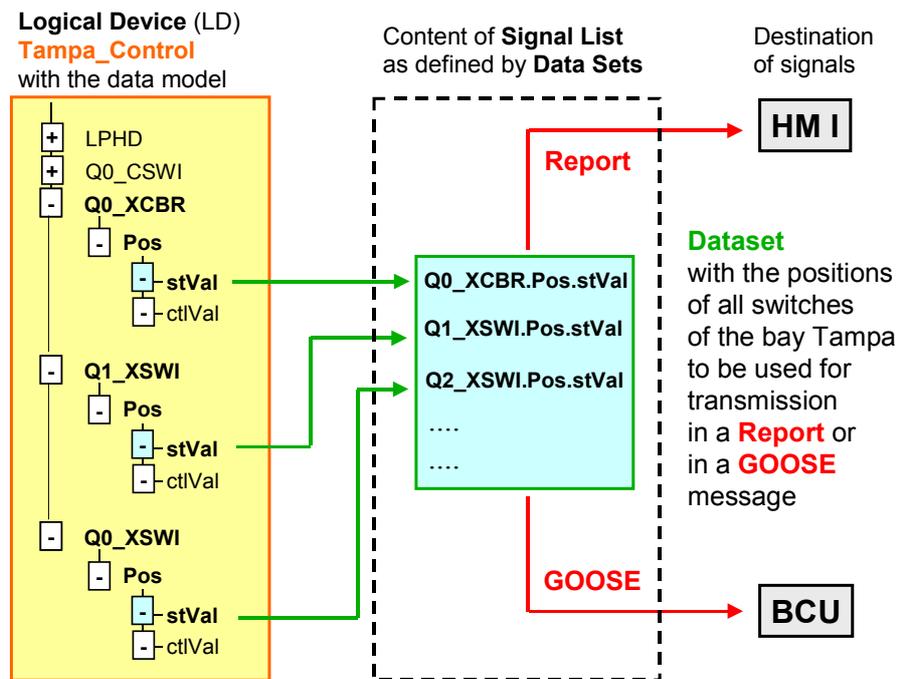
Figure 2 - The relationship between Data Model and Signal List

3.2.2   Signal List and Services

Issue:

There is a problem regarding the services defined in IEC 61850 since these services provide entries in the signal list, which are not seen directly in the data model or refer again and again to the same data object. Same holds also for the impact of services with attributes or parameters like the originator category or the operation direction.

Solution:

It has to be explained to the customer that steps of one service with different parameters may produce signal list entries acting at the same data object or on different attributes of this data object. Service data exchange and signals from conventional signal lists of the customers can be compared in one table (example see in Table 1).

OPEN sequence	Command service steps	Object	Status
Select breaker	SelVal_req	QA1_1XCBR.Pos.stSeld	UNSELECTED (FALSE)
Breaker successfully selected	Select_rsp+	QA1_1XCBR.Pos.stSeld	SELECTED (TRUE)
Command for breaker opening	Oper_req(off)	QA1_1XCBR.Pos.ctVal	OFF (FALSE)
Command successfully issued	Oper_rsp+	QA1_1XCBR.Pos.ctVal	OFF (FALSE)
Breaker has opened	Report_req(off)	QA1_1XCBR.Pos.stVal	ON>INTERMEDIATE>OFF
CLOSE sequence			
Select breaker	SelVal_req	QA1_1XCBR.Pos.stSeld	UNSELECTED (FALSE)
Breaker successfully selected	Select_rsp+	QA1_1XCBR.Pos.stSeld	SELECTED (TRUE)
Command for breaker closing	Oper_req(on)	QA1_1XCBR.Pos.ctVal	ON (TRUE)
Command successfully issued	Oper_rsp+	QA1_1XCBR.Pos.ctVal	ON (TRUE)
Breaker has closed	Report_req(on)	QA1_1XCBR.Pos.stVal	OFF>INTERMEDIATE>ON

Table 1 – Example for the relation between Service activities and Signal list entries

3.2.3   Same Data Model from all suppliers

Issue:

Some customers try to get offers with exactly the same data model from all suppliers. For all standardized data identification parts like LN class name, Data name and Attribute name, this can and is reached. All non-standardized parts like LD name, LD content and LN Prefix are defined by the individual software implementation of the manufacturer. If extensions are needed and made, the problem to implement a common data model is increased for the manufacturer. It looks that this requirement is based on the whish for interchangeability and for plug-and-play e.g. in case of SA extensions.

Solution:

Explain that identical data models cannot be reached beyond the standardized data name parts An example on LD level is given in Figure 3. The manufacturer A is grouping its protection functions for the line protection into 3 Logical Devices (LD), and manufacturer B into 1 LD. For control, manufacturer A is using 1 LD only, but manufacturer B is using 2 LDs. Manufacturer A is not using the prefix at all, but manufacturer B is grouping with the prefix LNs inside the LDs to get groups with common semantic meaning (see Figure 4).

Figure 3 – Modeling same Logical Nodes (LN) in different Logical Devices (LD)

It has to explained to the customer that these both solutions and many other ones are compliant to the standard. It has to be explained and maybe shown in the SCL file that these differences do not impact interoperability. The greatest problem for interoperability is if one functions needs some data, which are *not* provided by any other IED (see section about the tools below). This has to be checked by any System Engineering Tool as

mentioned below. The Logical Devices (LD) have not to be implemented into independent IEDs. Also Protection and Control may reside in the same IED.

An example for the modeling of a bay control unit (BCU) is given in Figure 4. All LNs reside in the same LD named Control. Switchgear related Q-numbers like QA1_1 are also used as LN Prefix for grouping the LNs inside the same LD. All LNs belonging e.g. to the circuit breaker have the prefix QA1_1 including the project specific data in GGIO. Same holds for the isolators or earthing switches identified by QB1_1, QB2_2, QB9_3, and QC9_4. All other LNs cannot be allocated directly to a switch but belong to the complete bay.
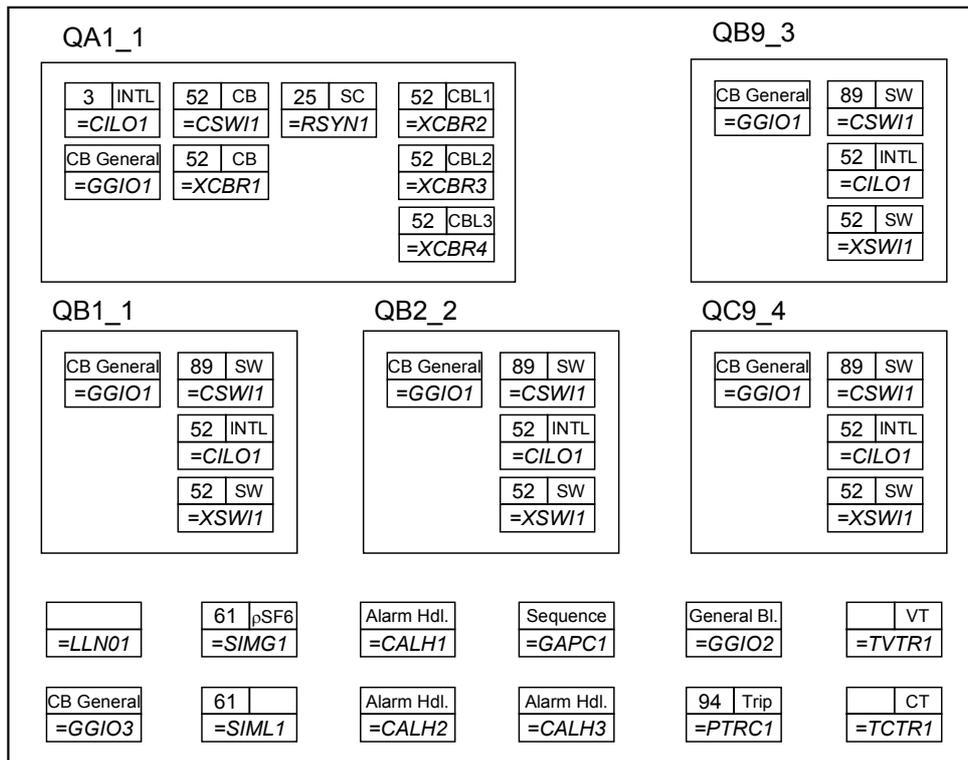
Figure 4 - Example for modeling a Bay Control Unit (BCU) by a single LD Control

3.2.4   Customer specific extensions of Data Model

<u>**Issue:**</u>

Regarding modeling, some customers request extensions of Logical Nodes by project specific data. In the scope of IEC 61850, extensions are possible but controlled by strict rules. For example, the name space concept has to be used. The alternative often proposed by suppliers is to use generic logical nodes instead, i.e. GGIO and GAPC which can be filled with all applicable data from the semantically standardized Logical Nodes. But using generic Logical Nodes, the semantic context of the LN class name is lost.

<u>**Solution:**</u>

First, it has to be noticed that according IEC 61850 it is mandatory to use first existing Logical Nodes, Data and Attributes if applicable. For the suppliers, any extension impacts the SW implementation at least on application level. Depending on the implementation concept the extensions may also have an impact on the firmware. In addition, the maintenance of extended data models has to be considered.

The following approach solves these problems. Logical nodes are only extended if it is a common requirement on the market of the supplier. Such extensions are also candidates for amendments of the standard. *Project specific extensions* needed by one customer only are provided with GGIO and GAPC. The semantic link to an existing LN is made by a common prefix (see Figure 4).

3.3   Configuration

3.3.1   The Role of the Standard

Issue:

Some customers request SA communication architectures according IEC 61850 under the assumption that these are given elsewhere in the standard. Same holds for common standardized tools used and provided by all suppliers.

Solution:

It has to be clarified that IEC61850 is not making any definition concerning specific communication architectures nor the configuration and engineering tools. It supports means to get SA systems with standardized data and communication. It defines with the Substation Configuration description Language (SCL) the format and the semantics to be used to interchange communication configuration information between the dedicated tools used by the different vendors. SCL allows not only describing communications but also the IED functional capabilities in the context of IEC 61850, the single line diagram and the relation in between.

3.3.2   Redundancy in Communication Architecture

Issue:

A common feature in specifications is to draw SA architecture with two parallel lines for busses and/or to state that the communication has to be redundant, e.g. by two ports per device.

Solution:

This is not new feature in Substation Automation. But in proprietary system, there was not so much choice in configurations as for IEC 61850 based systems using Ethernet. It has to be noted that redundancy is not defined in the standard for the time being. It was left to the "external" communication system. Different levels of redundancy can be designed. For example, an Ethernet ring already provides some redundancy. To request full redundancy means not only duplicated ports of IEDs, but also the duplication of Ethernet switches, of power supplies, etc. It will increase the cost of the system in any case. For the time being, redundant systems for IEC 61850 communications include some problems. They have at least proprietary link supervision in case of dual ports. They may provide some interoperability but no common level of redundancy.

Redundancy is basically a mean to get higher availability. To find solutions fitting exactly to the needs of the customers, a *scenario* with all expected failure modes and their impact should be worked out. Questions of the type what degradation is allowed for what time have to be addressed. This scenario has to be used for SA system design. Steps how to get solutions out of requirements are outlined in [8].

3.4   Protocol Converters

Issue:

Very often protocol conversions are needed between IEC 61850 and other protocols, especially for the NCC link. In case of migration, also parts inside the substation may need protocol conversion. The request is that the existing part should not be changed and new parts are according to IEC 61850.

Solution:

Protocol converters have no problems to map *data* from one protocol to another one. Protocol converters have also to translate the *services*. Basic read and write commands are simple translated but complex ones like the command service may be handled different in different protocols. IEC 61850 has standardized a select before operate (SBO) command with one SELECT and one OPERATE. If there is a three step SBO implemented in the other part of the system, this different service behavior has to be translated by the protocol converter also (example see Figure 5). The SELECT Open can be AND-connected in the gateway by the OPERATE Open to keep the intended command safety. A three step SBO command service in the IEC 61850 is against the standard and would need a work-around. Therefore, deviations from standardized services prohibit interoperability and have to be avoided.
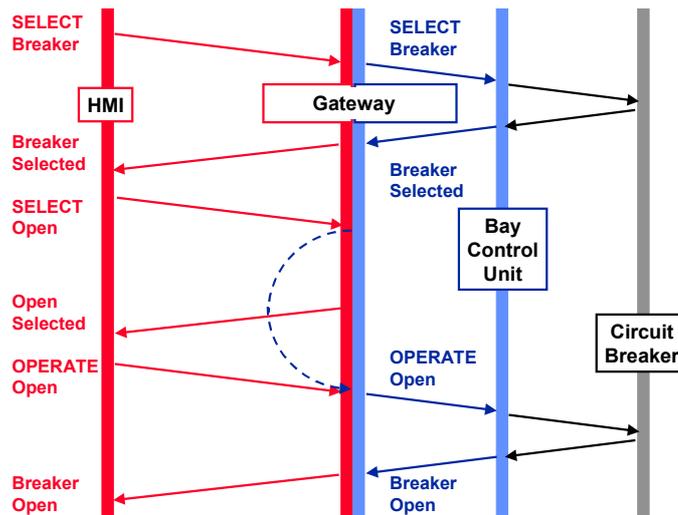
Figure 5 - Translation of three-step to two-step SBO service

3.5 Engineering and maintenance

3.5.1 The Role of the Substation Configuration Description Language

Issue:

Some customers assume that the use of IEC 61850, especially with an identical data model for all suppliers (see 3.2.3 above) provides some plug-and-play behavior.

Solution:

It has to be clarified that the data model defines only the source or server side of the communicating IEDs. For the description of all relevant SA parts the Substation Configuration description Language is provided by the IEC 61850 also. Every IED has to come with an ICD file, which describes its maximum communication capabilities in terms of the standard. SCL allows also describing the existing links between the devices and the bus (access points), the data sets and the rules (Control Blocks) for spontaneous communication (Reports, GOOSE, SV). The input section ("client part") of the IEDs is described and the single line including its relation to the SA system. All these needs cannot be fulfilled by plug-and-play at least for the time being. Engineering has to be done with appropriate tools (see Figure 6) allowing e.g. the consistency checks.

3.5.2 Tools

Issue:

Some customers assume that there are common tools specified by IEC 61850. Depending on their level of intended activity they ask for dedicated tools e.g. for maintenance.

Solution:

IEC 61850 is not specifying any tools but with SCL the data exchange format including semantics between tools. There will be competing tools on the market but as long as they support all relevant features of the standard their parallel use will not be a basic problem. For the time being dedicated tools as for maintenance have to be negotiated on project basis.
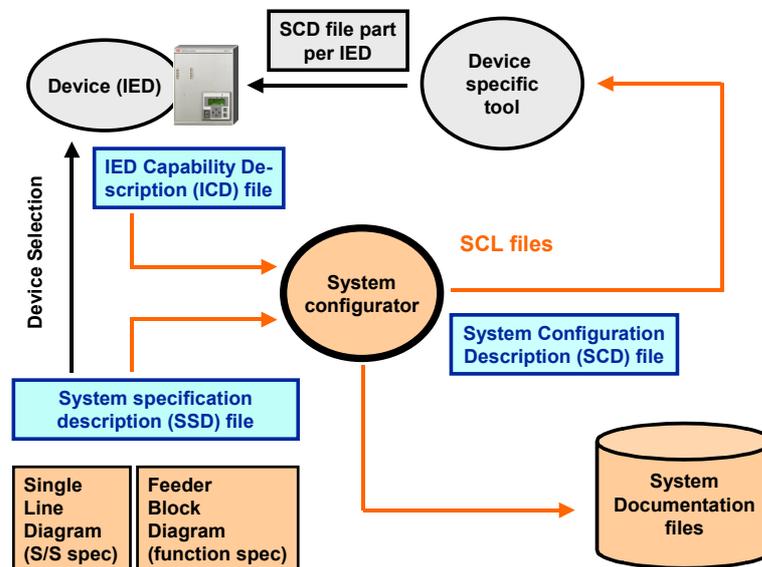
Figure 6 – Engineering work flow

4   CONCLUSION

Introducing IEC 61850 in SA means both the introduction of a new communication technology and a new approach to data modeling and services. With the specification of the first projects, some misunderstanding between users and providers had been experienced. The function specification is not changed but sometimes mixed with the specification of the data model and communication services. Most cases could be resolved by explanations only but sometimes the new approach has to be respected. To exploit the full benefits of IEC 61850, a more formal specification is recommended. More issues may emerge in the next future but with increasing acceptance of this standard and growing experience most issued will get common features in the SA specifications .

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