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SOME ASPECTS OF MIGRATION FROM PRESENT SOLUTIONS TO SA SYSTEMS BASED ON THE COMMUNICATION STANDARD IEC61850

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ABSTRACT
Today many substations exist with a multitude of different communication systems and architectures. Extension and retrofitting of stations are natural opportunities to introduce the IEC61850. It can be that an extended part of a substation is equipped with the new standard and then need to be integrated into the older part that is based on presently available communications. When retrofitting a substation, the substation may be supplied entirely with newer generation secondary equipment whereas the primary equipment remains based on a conventional solution. This will cause different migration steps. These migration steps will result in a requirement for protocol conversions and engineering. This paper shows with some examples how these migration steps can be made and the resulting requirements on data conversion, backward compatibility and engineering.

1 INTRODUCTION

The communication standard IEC61850 for interoperability in substations is designed for long lifetime and has also some powerful features like supporting the life cycle of a substation. This will push the introduction of the communication standard in the substations. In a few years time all new substations can be equipped from the start with equipment able to support the new communication standard. However, in the case of existing substations a stepwise introduction of the communication standard must be expected. This will be the case for a considerable number of substations, when we consider that the lifetime of a substation is up to 60 years and the high number of substation automation systems in use today. The manufacturers will soon start to offer secondary and primary equipment where the new communication standard is already implemented. Therefore, migration scenarios from present existing solutions will be an important topic during the years to come.

2 EXISTING SA

2.1 Definitions

In the present SA systems we have equipment on different levels of the substation. Further we have communication between the different levels. We will here define the levels for the scope of this discussion in the following way:

Station level is the upper level where centralised system computers, Human Machine Interfaces (HMI) and gateways (GW) for connections to Network Control Centres (NCC) are located.
Bay level is the middle level where the protection and distributed control equipment is located. The equipment is responsible for protection and control of the bay where they are located and may also include implicitly system wide functionality e.g. interlocking.
Process level is the lowest level where the switchgear equipment is located including the sensors and actuators that are necessary to monitor and operate the switchgear. Examples of sensors are the current and voltage transformers, and examples of actuators are the drive mechanism for breakers and isolators.

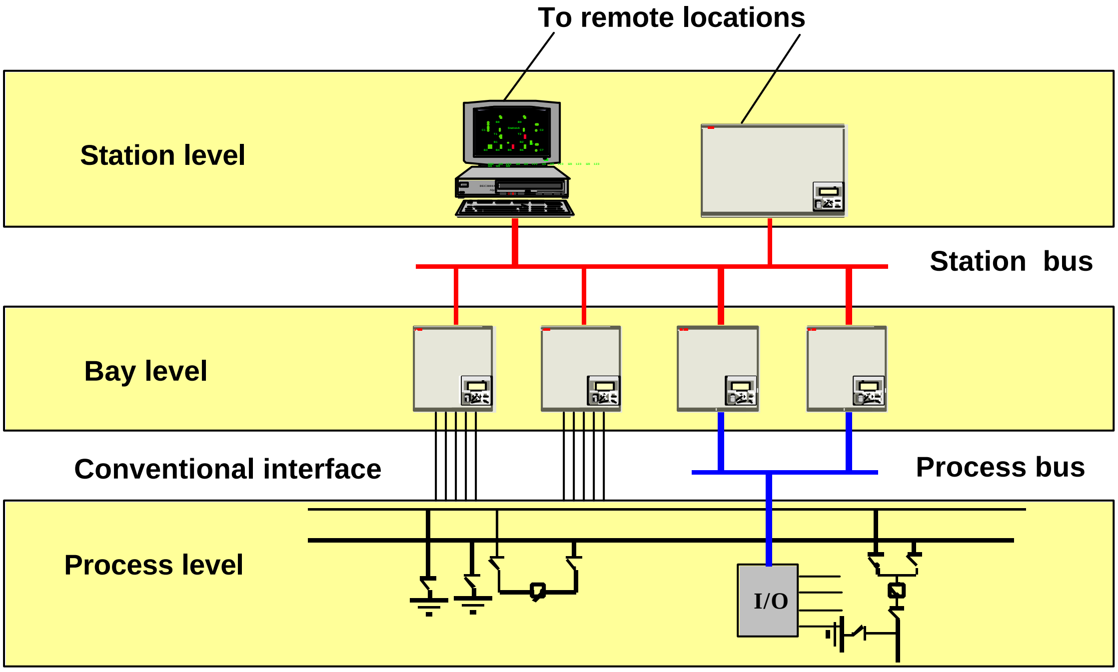

Figure 1 Substation levels and communication

All the above levels need to communicate via either hard wire or serial connections or networks. We define the different communication systems for this purpose in the following way:

Station bus is the connection between bay level and station level. This is a serial connection and can be of different topologies e.g. bus, ring, star.

Process bus is the connection between the process level and bay level (can also be connected to the station level). When we use process bus here it means a serial link between primary equipment and bay or higher levels. The link can be either point to point or of network type for one or more bays.

Process connection we use here to denote a hardwired connection between the process level and either bay or station level. We also use the term **conventional interface** to denote this interface to the primary level equipment.

2.2 Architectures

Based on the above definitions we now describe three different architectures used today for the Substation Automation.

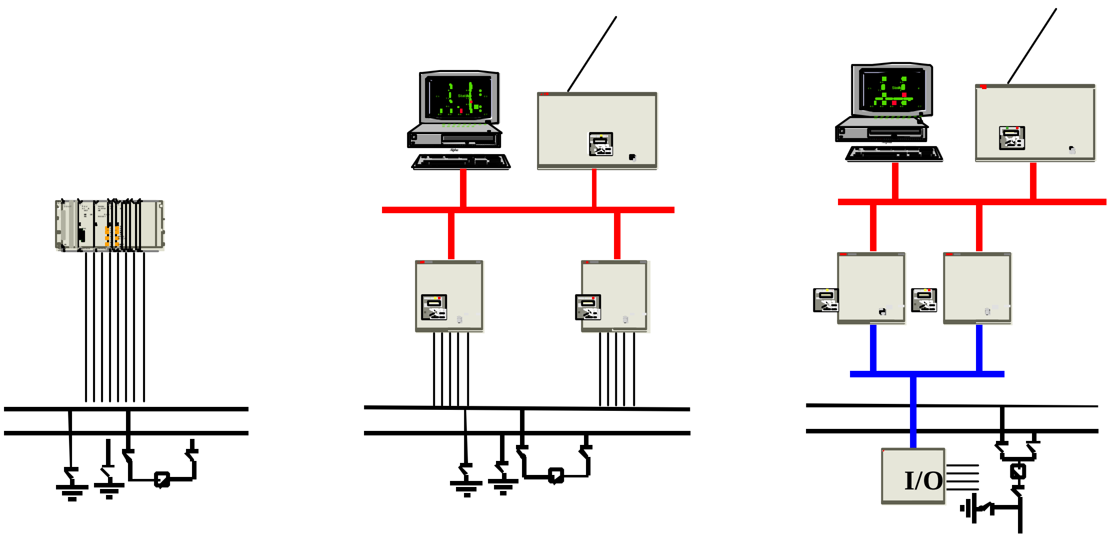

Figure 2 Centralised, decentralised and decentralised Process Bus examples

Centralised solutions are characterised by having one central element for computation, data storage and communication. We will here use a solution with one central RTU for control and monitoring functions to represent this. All applications are executed in the RTU, and all data from the process are brought to and stored in the RTU as necessary. The RTU is the single access point from the NCCs. If a HMI is used locally in the station this is also connected to the RTU.

Decentralised solutions are very common in present substation automation systems. They have a HMI and a gateway on the station level, all protection and control units on bay level and a conventional interface to the process level. The station and bay levels are connected via a station bus. In this solution most of the control and protection functionality is located on the bay level. The gateway is the single point of remote connection.

Decentralised PB solution is the third solution we define. It is the same as the decentralised solution above but with a process bus (PB) for the connection between the bay and process levels instead of the conventional interface. The process bus connects to intelligent sensors (electronic sensors) on the process level.

All communication buses are today more or less proprietary or at best de-facto standards.

3 FUTURE SA BASED ON THE IEC61850

3.1 The standard IEC61850

The IEC61850 is a new standard for communication in substations that supports all possible structures. This has been achieved through a breakdown of functions into their smallest pieces relevant to communication (logical nodes) and a consistent application level object modelling of the logical nodes.

Both the station and process level communication are covered by the standard. This enables the entire substation to communicate over one network defined by one and the same standard.

All communication based on the new standard is principally of peer to peer type, even if a client - server architecture is used. The communication network imposes no architectural limitations.

To support the configuration and maintenance of the communication network the standard supplies the Substation Configuration Language (SCL). The SCL is a formal way of describing the Substation and the secondary system from the communication point of view.

Application and communication are well separated. This is required because of the different life cycles. An application has a much longer lifetime than the communication and must therefore be protected from changes driven by advances in technology in the communication part. From the application level model requirements on the implementing communication technology are defined, which must be met by a concrete stack mapping, in the case of IEC61850 that to Ethernet, TCP/IP and MMS.

3.2 Replacement, extension and retrofit

How do we make the step from the present solutions to the solutions based on IEC61850? New systems that are built in some years time from now will have the possibility to use all IEC61850 based equipment and are therefore outside the scope of this paper. Also in the cases where a complete retrofit of all the secondary equipment is made in one step the replacement will require very little in terms of system migration, although some amount of training must be invested to understand the IEC61850 concepts and possibilities. Physically here the only requirement is to interface to the primary levels with a conventional interface, and this is a backward compatibility issue for the bay level equipment. Nevertheless, the question how to safeguard the existing efforts in communication engineering is left.

Replacement of part of the station devices may lead to a migration. When single devices are replaced due to maintenance there are two cases to distinguish. When spare parts are available of the same type there is no change in the systems. In the other case where new, backward compatible, spare parts are used they will mostly have new functionality as well and this can lead to a retrofit of part of a station.

Retrofit can imply smaller or larger changes to the installed equipment. Typically the secondary equipment is replaced more often than primary equipment. When the primary equipment is changed, this may be partial replacement only. The most interesting scenario here will probably be the replacement of secondary protection or control equipment which implies “bay level first” type of scenario.
Extension is when we have an existing station based on conventional technology that need one or more extra bays having intelligent sensors and actuators instead of the conventional interface of the existing switchgear. It can also be the introduction of one or more (extra) connections to NCC, where the new gateway supports mainly the IEC61850 for station bus connections, or an IEC61850 based protocol shall be used to the NCC or to some monitoring or maintenance centres.

4 MIGRATION

The most interesting migration scenarios will be the ones where the new IEC61850 based equipment is introduced in steps to existing equipment. There are two main driving factors for this: retrofit and extension of substations or of system functionality. With the long life cycle of primary equipment compared to the secondary equipment this will be a need for years to come, especially if the advantages of the new standard on system level shall be explored before complete replacement of the substation secondary equipment.
Only the first step of migration will be addressed here, the reason for this is that the further steps of migration can be described by combining the below scenarios as needed.

4.1 Different cases of stepwise migration

We will here illustrate the impact of migration on the different architectures defined above by means of examples in scenarios. We use three different types of migration scenarios. They are described briefly in the following text. In Table 1 the resulting needs for data conversion in a substation are summarised. Note that some of the migration scenarios cause more than one data conversion requirement in the system. For each scenario the upper part describes the needs for the station bus and the lower one that for the process bus

Migration starting at: **Type of solution**	**Process level**	**Bay level**	**Station level**
Centralised	-	-	-
	IEC61850 process bus on process level to conventional interface on bay level	-	-
Decentralised	-	IEC61850 station bus on bay level to proprietary station bus on station level	IEC61850 station bus on station level to proprietary station bus on bay level
	IEC61850 process bus on process level to conventional interface on bay level	IEC61850 process bus on bay level to conventional interface on process level	-
Decentralised PB	-	IEC61850 station bus on bay level to proprietary station bus on station level	IEC61850 station bus on station level to proprietary station bus on bay level
	IEC61850 process bus on process level to proprietary process bus on bay level	IEC61850 process bus on bay level to proprietary process bus on process level	-

Table 1: Summary of data conversion requirements

4.2 Migration starting at the process level

We will divide this case into an extension and a retrofit scenario. First we look at a case of extension of a station where one or more new bays are added to an existing station. The new primary equipment that is introduced for the extension is based on intelligent sensors and actuators. We still want to use the same type of bay level equipment for protection and control in the new part of the station as we are using in the existing part now. The existing part of the process level remains with the same type of interface and the new part of the process level will have an IEC61850 process bus interface. On the bay level all equipment have the same type of interface as before the extension both in the existing part and the new part.

In the case of retrofit we will replace conventional current and voltage transformers and instead introduce intelligent sensors with the IEC61850 process bus interface. It is our intention to keep our secondary equipment as is. Only data from the new sensors is concerned with the replacement, all existing binary data interfaces are left as they are. We have a process interface on the process level for analogue data based on the IEC61850 while all bay level equipment remain as they were. Both extension and retrofit as described here will generate a need to convert data between process level and bay level.

4.3 Migration starting at the Station level

On the Station level we decide to extend the remote connection capability with a new protocol that is not available in the present gateway or RTU. The new protocol required on station level towards the NCC will require a new gateway between station bus and NCC; this new gateway supports the IEC61850 station bus but not the proprietary station bus presently used. There will be a need for data conversion between these station busses. Once this conversion is introduced the door is open to add more IEC61850 equipment on the station level without any further conversions needed. Therefore this is also the preferred way in case of retrofit of the station level HMI. For the centralised solution this is more a system replacement than a migration and is not relevant here.
Introducing a gateway in series with the existing gateway can also solve this migration. This does not bring any IEC61850 migration issues though, and is therefore not interesting for the discussion in this paper.

4.4 Migration starting at the bay level

Here we need to replace a bay unit for reason of maintenance or because of additionally needed functionality. The replacement only concerns a part of the bay level and the rest will remain as is. The new bay unit is not a one to one spare part but has a process bus and station bus according to the IEC61850. Here two data conversion needs arise. One is the conversion between the existing station bus and the IEC61850 station bus, and the other is the conversion between the existing process level interface and the IEC61850 process bus of the new bay unit. The centralised architecture is not relevant here since it has no bay level equipment.

5 SOLUTIONS TO THE MIGRATION SCENARIOS

5.1 Common aspects of the solutions

So far only direct data conversions have been considered. Backward compatibility as well as two step migration scenarios has so far not been considered. We will discuss this in the following.

The driving factor for backward compatibility is that it pays off. This in turn can be translated into that it is needed for some time to come and also has a limited maintenance cost. To motivate the backward compatibility we need to address these issues.

Firstly the equipment on the process level has a longer life cycle than the equipment on bay and station levels. Secondly the number of existing solutions between bay and process levels is of a magnitude less than between station and bay level. In fact the conventional interface is a de facto standard and by far the most commonly used

today, and will remain if the benefits of the new technology can not be exploited. This would give that it makes sense to keep the conventional interface on bay level equipment as a backward compatible solution for connection to the process level. This also solves the case of retrofit of bay level equipment when the switchgear remains.
Exception here is when retrofitting the bay equipment where the switchgear has a proprietary process bus. Then backward compatible bay equipment may only be available from the switchgear supplier. Here either a data conversion or a retrofit of both process and bay level may be the solution.

In Table 1 we also find data conversion on the process bus level from serial interfaces in the process level to a conventional interface on bay level. This conversion is both very expensive and also technically inefficient and is likely to be solved in another way.
Further impact from the differences in life cycle length between the equipment may lead to that there is bay equipment forward compatible with the IEC61850 process bus, already installed, at the time when the primary equipment is updated.

For the case where voltage or current transformers are replaced independently of the rest of the primary equipment (most likely for AIS), the IEC61850 process bus will be needed sooner than dictated by the primary equipment life cycle. This will require a migration of the bay level equipment at the same time as the voltage or current transformers are replaced. This will be another motivation to have a backward compatible process interface in the bay equipment in parallel with the IEC61850 process bus. Thus the need for data conversion between bay and process levels is reduced to the case where proprietary process bus solutions are installed today – which is not very often the case.

For the proprietary process bus a data conversion to the IEC61850 process bus may be necessary. As alternative the bay level equipment may be backward compatible and have the proprietary and IEC61850 process busses in parallel. This may however be limited to the bay equipment supplied by the switchgear manufacturer that owns the proprietary process bus. For other cases with a proprietary process bus, retrofit of process and bay levels at the same time will be the most likely solution.

The station to bay level is today characterised by a large number of communication solutions and the equipment on both station and bay level also has a relatively short life cycle. This leads to the conclusion that introducing backward compatibility with respect to the station bus will be less common. There is a definite advantage of converting the proprietary station bus to the IEC61850 station bus with a gateway (that can of course be redundant if the proprietary station bus supports this) and thus open the existing system to the IEC61850 world. There must be gateways implementing both IEC61850 client and server functionality to cover all requirements.
In Table 2 below suggested solutions for each case of the migration scenarios are listed.

Migration starting at: **Type of solution**	**Process level**	**Bay level**	**Station level**
Centralised	Solved by migration of the central computer at the same time as the switchgear (either a replacement or the new computer in parallel to the existing)	-	-
Decentralised	Solved by migration of the bay level at the same time as the switchgear	A gateway for conversion between the IEC61850 station bus in the new bay equipment and the proprietary station bus used by the existing equipment. (the gateway needs an IEC61850 client) For the process level backward compatible bay equipment is needed.	A gateway for conversion between the IEC61850 station bus in the new equipment and the proprietary station bus used by the existing equipment. (the gateway needs an IEC61850 server)
Decentralised PB	Solved by migration of the bay level at the same time as the switchgear / process level. A gateway for data conversion may also be used here.	A gateway for conversion between the IEC61850 station bus in the new bay equipment and the proprietary station bus used by the existing equipment. (the gateway needs an IEC61850 client) For the process level backward compatible bay equipment with the proprietary process bus in parallel to the IEC61850 process bus, or migration of the process level equipment at the same time. A gateway for data conversion may also be used here.	A gateway for conversion between the IEC61850 station bus in the new equipment and the proprietary station bus used by the existing equipment. (the gateway needs an IEC61850 server)

Table 2: Suggestion for solutions to the migration scenarios

5.2 Two solutions for the station level

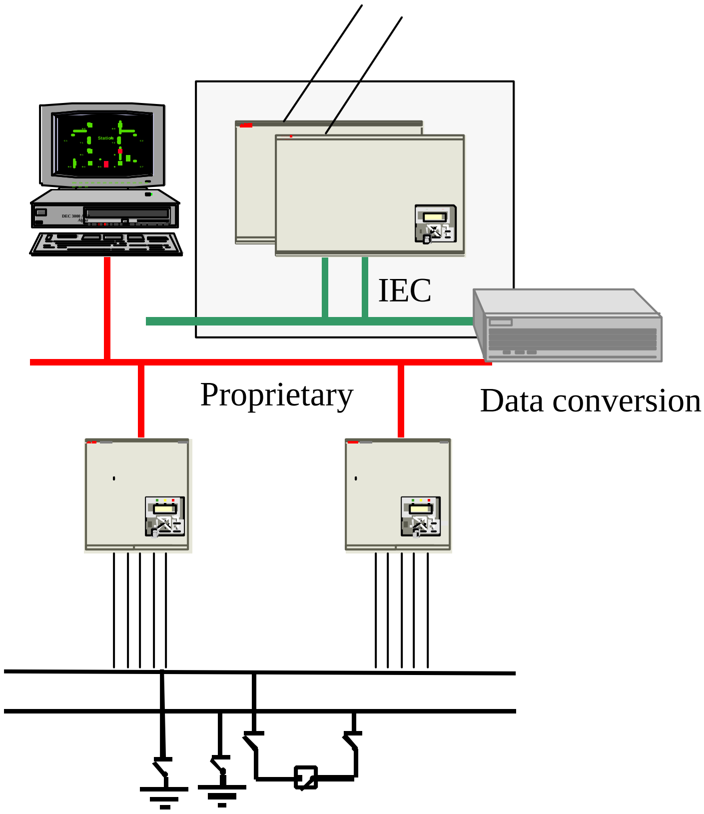

Figure 3 Migration starting at station level with one or more new IEC61850 based gateways

Above, in Figure 3, is the solution with an IEC61850 – Proprietary data conversion for the migration of one or more new gateways with IEC61850 station bus (shaded area). The data conversion device supplies all data coming from the proprietary station bus as an IEC61850 server to the IEC61850 based station level. The conversion between the proprietary existing station bus and the new IEC61850 station bus is only needed once in the station and then allows including more than one gateway or other station level equipment. Each new added unit must be engineered and configured, but by using the object model and mechanisms of the SCL this can be done in advance. The mapping from proprietary to IEC61850 object model needs only be done once for each type of unit.

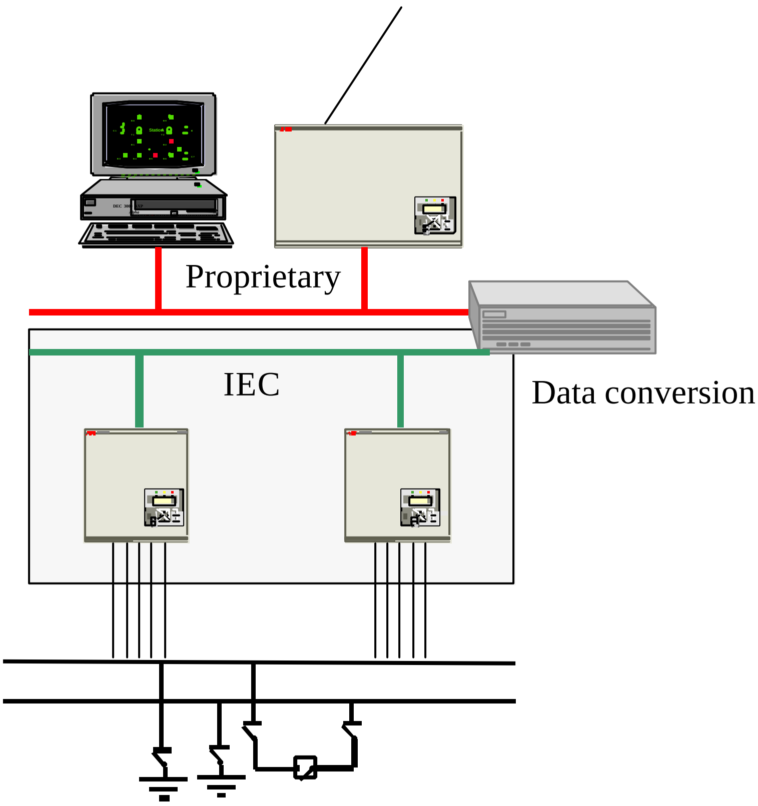

Figure 4 Migration starting on bay level with one or more new IEC61850 bay devices

Above, in Figure 4, is the solution with data conversion between proprietary and IEC61850 station bus for migration of new bay devices that support the IEC61850, migration starting at the bay level. The shaded area is the new equipment. The data conversion unit contains an IEC81850 client, which provides the IEC61850 data to the proprietary station bus. Also here the data conversion need to be introduced only once and can then support bay devices in the entire station. Note that the data conversion unit has the same architecture as an gateway from IEC62850 station bus to an NCC. In case that the proprietary station bus is based on a (industry) standard protocol, this data conversion device might be available as a standard IEC61850 based NCC gateway.

5.3 Summary of migration measures

The data conversion requirements can be formulated in terms of data conversion devices (gateways). On station level there will be a need of one gateway for each type of proprietary protocol used today. The gateways need to have IEC61850 client or server functionality as well as corresponding proprietary protocol functionality.
Backward compatibility with the conventional interface in the new bay equipment will be the most likely solution for the connection between bay and process levels. The only cases where gateways may be introduced here are where proprietary process busses are used today.

Now data conversion is not only a matter of mapping bits and bytes, in fact in the IEC61850 it is just about everything except mapping bits and bytes. The SCL Station Configuration language is a powerful aid in describing a station and its functionality from the communication point of view. This aid together with the object model, service definition and clear separation between application and communication, which are all fundamentals of the IEC61850, will lead to a reduced and easier way of handling the engineering issues. It can be used even before an IEC61850 based bus is really introduced into the station. The more similar the proprietary and the IEC61850 solutions are (service types, data types, and function and object models) the easier the implementation of data conversion and its engineering will be.

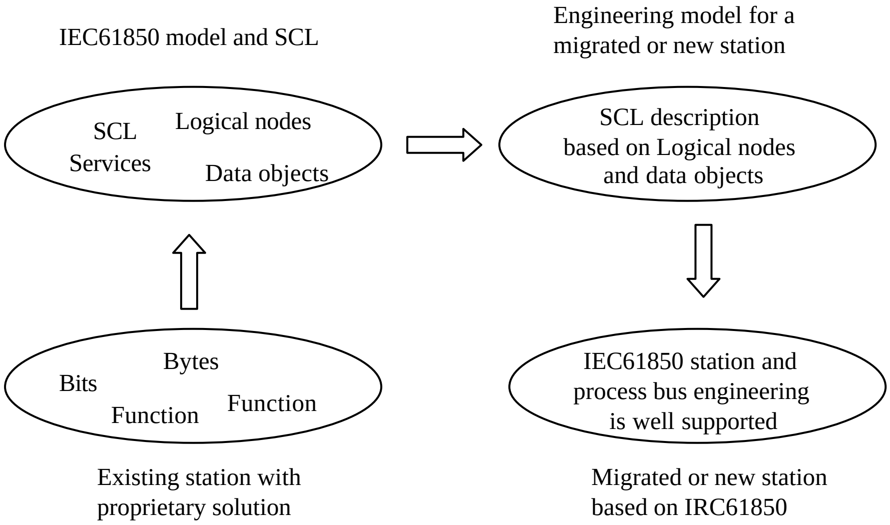

Figure 5 Engineering from proprietary to IEC61850

Once a modelling of the existing functionality and data has been made from the proprietary world to the IEC61850 logical nodes and data objects all the rest can be done on the application level and supported by engineering tools. By associating the existing functions with the logical nodes and map the proprietary data to the IEC61850 data objects once, the base for all further engineering is laid. A big advantage is that all this can be done well ahead, all the characteristics of the IEC61850 are well known, and thus the amount of work during the actual migration phase is reduced drastically.

6 CONCLUSION

Life cycle characteristics influencing the driving factors of extension and retrofit will lead to a migration from present communication solutions to one based on the IEC61850. It will go faster on the station and bay levels than on the process level. There will be a considerable need for data conversions for the station bus due to the fast migration and also due to the large number of communication solutions in use today. On the Process bus level the life cycle and conventional interface standard will favour backward compatible bay level equipment and lead to a limited amount of data conversion as well as a slower pace of migration. The backward compatible bay level equipment with the IEC61850 process bus in parallel will be needed soon in order to be available in the station before the retrofit of the switchgear takes place.
The ease with which the needed data conversion can be made is largely dependent on the characteristics of the proprietary protocol used today. It is clear that the more similar the present protocol solutions are to the IEC61850, the easier it will be to realise the data conversion. In all cases the preparation for migration can start already now by modelling the present communication solutions on all levels to the IEC61850 using the Station Configuration Language. This can also be initiated and synchronised with the modelling of the power network according to the IEC61970. One can say that the scope of the IEC61970 ends where the scope of the IEC61850 starts, and used together they will give a seamless model of the entire network including the substation automation.