Standard platform for integrated soft protection and control
A. Johnsson, J.E. Söderström, P. Norberg, and A. Fogelberg, Sweden

Abstract—Increasingly powerful processors for substation automation systems make it possible to integrate and process many functions for both protection and control in the same computer. This article describes possibilities, experiences and challenges for a standard platform for integrated soft protection and control of AC substations. The benefits of such a solution have been described in several papers [1], [2]. Field tests also show that it works in reality. With the development of the process bus IEC 61850-9-2 there is now also a solution for connecting distributed I/O’s in a standardized way. The possibility to buy equipment from different vendors leads to competition and decreased prices. The next step is to create a scalable environment where the functions can adapt to the needs in the specific substation and the present situation in the network, ie future smart grids. Most of these functions can be implemented with the existing distributed solutions based on IEC 61850 but the development of an open system platform makes it possible to integrate functions from different vendors and thus create full flexibility. The article describes possible benefits as well as potential challenges before reaching a totally integrated solution.

Index Terms—Automation, communication systems, control systems, digital systems, protection, substations.

I. INTRODUCTION

For more than a decade computers control HVDC-installations all over the world from some tenths of MWs to thousands of MWs. The computers control not only the inverter signals but also the surrounding DC station control equipment. But computers are not yet generally used in AC T&D substations. HVDC/SVC have often been a forerunner in control equipment for power facilities and have since a long time strived for a higher degree of integration and computers were early introduced.

Around 10 years ago Vattenfall bought one of the first HVDC-Light installations (50 MW, 80 kV) for the island Gotland in the Baltic Sea. One of the rectifier terminals was build close to an existing AC transformer-station. Because a lot of signals were common for the AC control and the DC control it was suggested to see if the DC control computers could handle some of the AC bays that were vital for the converter. After adding special software for AC protection and control it worked fine and it was decided to test the same idea in full scale for some AC substations on the island Gotland.

Figure 1 shows the main principle of the system. Protection and control functions are integrated as software modules in an industrial PC. Several I/O’s, typically one for each bay, are connected to the industrial PC using a communication bus.

Based on the positive experiences from the AC substations at Gotland, Vattenfall decided in 2004 to demonstrate a fully integrated soft protection and control solution by replacing existing old protection and control equipment in the 130/40 kV Ulricehamn substation. The product used was developed as control equipment for HVDC and SVC applications and have been used since the late 90’s. The installation was commissioned and taken into operation in September 2005.
The Ulricehamn project provided possibilities to evaluate the basic functions in integrated soft protection and control and how new functionality can be developed and implemented. Furthermore, it gave a chance to identify conditions and criteria for implementing computerized control equipment based on software based (soft) protection and control.

II. BENEFITS OF INTEGRATED PROTECTION AND CONTROL

The benefits of integrated protection and control have been described in several papers and periodicals [1], [2]. The soft protection and control concept with standard computers has great potential, for example:

- New protection schemes or external functions could easily be added or copied.
- Faster fault clearance by adding special algorithms
- Other novel station functionality is easy to realize, for example internal self-control of the station
- Simplified handling of installation and testing
- Easy to export data for further analysis like fault records or power quality.

What is also important is the fact that it is only the brain of the station that has to be changed to have all the possibilities above. The old assets in the switchyard like transformers, breakers and more can stay as they are. What you need are I/O units to go from analogue to digital.

With the system installed, new objects can also easily be added. Another important benefit is that the system can always be updated with the latest version of the system and application software. This can be done in all substations. An improvement in a protection function can immediately be updated in all places.

It is important to point out that most functions and other possibilities described in this section can also be implemented with other modern protection and control concepts. Especially in case a complete new substation is built. However, some advantages are specific to the integrated PC based concept.

III. EXPERIENCES FROM REAL IMPLEMENTATIONS

A. General experiences and results

The control system that was initially used is a fully integrated system where all control is handled by software on standardized hardware and software platforms. By collecting all the signals in the substation in one I/O rack then protection, control, fault recording, and PQ-registration, for example, could be handled in one control computer. For small stations one computer could be enough, for bigger two working in parallel could be used and for the biggest there may be a need to add more depending on the number of systems to control.

Today 5 test installations are in operation in Sweden and the oldest has now been running successfully for more than 8 years. The biggest installation so far was inaugurated in autumn 2005 at a 130/40 kV substation on the mainland.

Different configurations have been used in different installations. So far the systems have worked excellent. The installed systems have met the requirements on availability and reliability set up for each of these installations.

B. Examples on specific experiences

All indications and measured values are only connected once, and then the signals could be used several times in the computer. This makes the physical connection easier, but there is more programming in the office. New functions are comparably easy to make, because all signals may already be in the system. All that has to be done is some programming. An existing function block library can be used, and combined into new functions. This has proven valuable during project development. New protection functions have been added very late in a project. The delivery time for these new functions consisted of the time needed to start the development tool, open a menu and click on the function blocks needed, add them to the design drawing and connect the appropriate signals.

It is possible to do testing directly in the computer in the office using a debug mode, before running live. The development environment for the first systems is vendor-specific. However, software functions are also available from other vendors. A program made by an external manufacturer has been integrated in the system at Gotland.

The system has a Protection Action Matrix (PAM), see Figure 3, to configure which protection shall trip which breaker. This makes it easy to change the settings. One of the stations was equipped with two busbars, and during the work all equipment was fed by one bay. It took just 5 minutes to make these changes in PAM instead of a week for changing the wiring.
During testing of advanced conventional protection relays it can today take a long time to verify that the right protection functions works, and that a reserve protection do not react, with an incorrect trip as a result. With the system presented in the paper it is rather easy to decide what shall happen during testing, because it’s possible to freely control the trip signals in the PAM. This means easier and faster testing especially in a complex system.

A few systems will not affect the organisation of the work, but individual work processes are affected. There is a shift from work in the field to work in the office. During commissioning less tests are needed at site, at the substation., and during operation fault analysis, power quality analysis and historical trending can be performed on the collected data.

The personnel may find it interesting to work with new technology. It increases the competence of the existing people. But the new technology may also be considered as a threat. It requires some new skills and some new knowledge from the personnel. The experience from Ulricehamn shows that maintenance staff that were not involved in the testing and commissioning of the substation felt uncomfortable with the equipment. All maintenance work was forwarded to the one person that was involved in the commissioning of the station, even though a specific task was not related to the new protection and control system.

IV. ALTERNATIVE TECHNICAL SOLUTIONS

A smart substation is characterized by several benefits such as less hardware, full flexibility to combine functions/equipment within the system, the possibility to cost-efficiently implement more sophisticated protection for meshed grid, remote reconfiguration, remote management, remote maintenance, increased information supply to supervising systems etc.

Smart substation functions can be fulfilled in two ways:
1. Distributed IED: s based on IEC61850, which is what the vendors are applying today.
2. The integrated concept which is a further development of the Ulricehamn concept

Both ways require further development efforts to fulfil customer requirements.

V. PRESENT SOLUTIONS WITH IEC 61850

With the development of the process bus IEC 61850-9-2 there is now a solution for connecting distributed I/O’s in a standardized way. The possibility to buy equipment from different vendors leads to competition and decreased prices. When reviewing the criteria for building new/refurbishing substations in today’s market situation it is clear that the direction is to use IEC61850 as the design base.

The IEC 61850 standard allows for composition of new functionality based on one or several IED: s, which is an enabler for the smart substation. Not to forget, the standard allows the use of existing functionality in new ways through the ability to communicate in a standardized way.

The standardization of communication also opens up for new work processes in terms of for example remote access to station functionality and collection of process data to central systems. There are also no inherent restrictions on centralizing of functions in the standard and this is taking place already as vendors are adding more and more functions to single IED: s.

There are still gaps regarding the process bus in both the IEC61850-standard and the equipments from vendors (primary, and secondary). Commercially available and fully developed process bus is a crucial step to fulfil the functions expected of a Smart Substation with this concept. The vendors also don’t fully implement and apply other functionalities supported by the IEC61850-standard. These functions have to be identified and implemented.

To fully benefit from the value offered by the standard, one needs to apply it in a bigger context, where all aspects are considered and deployed for maximum value. To be able to specify, procure and operate with optimal functionality and maximum cost efficiency, internal competence/know-how and processes needs to be developed.

The challenges with this standard are several:
• The standard is not fully mature (the vendors still have their own interpretations of it)
• Equipment ready for the process bus are still lacking in numbers
• The users have to obtain a deeper practical understanding of the intended design process behind IEC61850
• Utilities have to develop their own processes of specification of demands design, procurement, test, deployment and maintenance, and
• Utilities need to define the architecture that is necessary for them to make the smart substation a part of the smart grid and associated upper level information systems.

Implementation of IEC61850 is a prerequisite for deploying the integrated software P&C system, in order for the smart substation to be an integrated part of a smart grid. The technical design of the SA has to be specified more in detail than just functional requirements, which affects the procurement strategies.

VI. STEPS TOWARDS INTEGRATED PROTECTION AND CONTROL

A leading idea to form a smart substation concept is to integrate protection and control in one or more industry computers, thereby creating a standardized platform that will allow the protection & control functions to be flexible and possible to upgrade for a prolonged lifecycle. The goal is to create a scalable environment where the functions can adopt to the needs in the specific substation and the present situation in the network, i.e., future smart grids. Most of these functions can be implemented with the existing distributed solutions based on IEC 61850 but the development of an open system platform makes it possible to integrate functions from different vendors and thereby create full flexibility.

The implementations in Ulricehamn and Gotland are examples of the integrated solution. In order to reach the vision of the totally integrated software-based P&C system, the challenge is to develop the existing concept further to a standardized platform open for different vendors. To increase competition and thereby lower costs, the coming requirements on the future smart substation concept must be vendor independent. Keywords for smart substation architecture are interoperability, interchangeability, and standardized communication protocols. Since there is no complete standard for software integration today, the development of this solution must be made as cooperation between customers and suppliers. The integrated solution should also be based on IEC61850 for interfacing with external devices.

The software that has been used so far is optimized to handle converter control but not ac transformer stations. According to the manufacturer, further development is needed before it can be introduced as a general PC solution.

The computer operating system should have a real-time kernel in combination with a general purpose operating system. System software and application programs for the different protection and control functions run on top of the operating system, as presented in Figure 4. A runtime execution environment (RXE) must be built on an established real-time operating system and platform. The RXE provides published application program interfaces (API) to Virtual IEDs for execution and I/O. The virtual IED component shall have an IEC61850 interface, use published APIs from RXE, and shall provide published APIs for Function/Logical Node. The Function/Logical Node use published APIs from VIED. The soft protection and control tool shall be open for customers use, both programming and configuration. It provides a library for Function and VIED code, for software reuse. The tool shall adhere to IEC61850 as an IED configuration tool.

Different computers are connected to the communication network, connecting to the station control and monitoring system that may include an industrial PC with a keyboard and monitor. The computer has to have a database for the storage of events and a communication protocol converter (gateway workstation) for connection to control center systems.

A standardized process bus is a prerequisite for the development of a commercial product. The introduction of the process bus IEC 61850-9-2 will open up the possibility to use the same I/O modules for several systems. This increases the flexibility and allows for introducing additional systems.

In the future, the time it takes to replace an existing integrated system with a new integrated system will most likely be much shorter than today. Less reorganization of cables and the possibility to reuse the existing I/O card will shorten the installation period.

The possibility to upgrade the application and system software remotely is a useful application, but there is a concern regarding IT security. This needs to be handled with care, with a possible solution being an annual visit to each substation with a CD update.

Communication provides the means for a more flexible allocation of functions. The substation automation system for one station could be integrated in the system in another substation. Input and output signals for several stations could be integrated in a centralized multi-substation protection and control system.

Communication together with computer power in the stations means that today’s modern decision tools, like RCM systems, easily can get information that is vital for the asset manager of the system.

The project team behind the existing installations concur to the vision of a totally integrated software protection & control system. This should lead to a system that, provided the necessary standards are in place, would be open for functional development in a cost-efficient environment. The utility business would come to see new vendors in the area of software functionality and a more vivid competition, thus gaining in functionality/flexibility and decreased investment...
costs. On the other hand, it would lead to increased demands, on the customer's own responsibilities for process security as well as the customer's internal working processes. Also noted is that a totally integrated software system would increase the complexity of maintenance. Software renders upgrades by its nature and in a complex system this is a challenging task to perform.

VII. CHALLENGES

Previous paragraphs in this paper have described possible benefits with a totally integrated solution. There are also some potential challenges before reaching a totally integrated solution.

A big factor in achieving the goals is standardization in the form of IEC61850. It defines a flexible architecture for today's and future functions, based on the foreseen needs of the smart grid. Cost efficiency in procurement, implementation, deployment and maintenance are depending on the use of standards, in order to ensure the right level of the demand specification, competition between vendors and competence supply in maintenance.

An important functional step in the standardization is the emerging process bus, which allows full freedom in choosing and connecting different functions to each other. The communication interface can be moved further out in the process, and several signals can be merged in one unit, as shown in figure 5. This part is in need of more pronounced demands on the vendors, in order to increase the supply of equipment. This is a responsibility of the utilities to adhere to in order to make the vendors push their development.

The vision of the future protection & control system is the totally integrated software solution. This concept would mean even more flexibility in defining new functionality as well as standardized hardware (e.g., lesser costs) in exchange for new challenges in becoming a software buyer. This is a concept that is not well established with the big vendors today, even though some interest can be detected. The concept requires more standardization work to be done in order to become widely available, even though the concept would be an extension of IEC61850.

All the above conclusions can be translated into the following needs:

- Utilities must become experts in applying the standards of IEC61850 with regards to design, procurement, test, deployment, and maintenance.
- Utilities must become expert buyers of stations based on IEC61850
- Utilities must push on the vendors to produce more equipment for the process bus, both by cooperation and by demands in procurement.
- Utilities should further investigate the possibilities of a totally integrated software solution for protection and control, in the aspects of requirement analysis, technology evaluation, market situation, and strategy.

While the protection and control systems in the existing installations with a single vendor show reliable functionality, one challenge is to achieve the same reliability and functional integration in an environment with software functions from different vendors. Verification and warranty for implemented functions have to be considered.

VIII. CONCLUSIONS

The vision of a totally integrated, software-based Protection & Control system is based on the experience of several installations in Sweden. The results from the projects show several benefits that would be of great future interest for utilities, such as less hardware, full flexibility to combine functions/equipment within the system, the possibility to cost-efficiently implement more sophisticated protection for
meshed grid, remote reconfiguration, remote management, remote maintenance, increased information supply to supervising systems etc.

A smart substation is a part of a smart grid, which means that there need to be a coherent architecture all the way from the substation up to the supervising/administrative systems like SCADA, network information systems, distribution management systems, power quality monitoring etc.

A wider installation could promote some novel approaches regarding functionality, instead of using the same conventional thinking with new technology. Today’s functionality is often a result of yesterday’s limitations in processing and communication capacity. It should be possible to build smarter at a low cost. A problem with a function can be immediately corrected without changing any hardware. Increased use of standard industrial computers and standard I/O modules will open up for competition where several suppliers may offer equipment.

The soft protection and control system is a future replacement for the vendor IED’s used in today’s design of control systems. The new system must be adhering to the IEC61850 standard with regards to communication between functions (station bus) and communication with primary equipment (process bus). This can be done as a part of the runtime execution environment and thereby ensuring that the system becomes a part of an IEC61850 architecture. Thus, the findings suggest that the soft protection and control system is a replacement control system that shall be a part of an IEC61850 architecture to ensure standardized communications, both within the station as well as with supervising systems.

A standardized process bus is a prerequisite for the development of a commercial product. The introduction of the process bus IEC 61850-9-2 will open up the possibility to use the same I/O modules for several systems. This increases the flexibility and allows for introducing additional systems.

The product used so far is designed for HVDC-control and it was modified to deliver needed functionality for the Ulricehamn AC-station. A new design needs to be accomplished (instead of a design modification).

Software based, totally integrated, protection & control system must be a hard real-time system, capable of running many different execution processes in a predictable and deterministic manner. This is the normal base for a process control system and there are many solutions for hardware and operating systems, but not in terms of standardized execution environments. This means that the major task is to design and define a software runtime execution environment where the software functions can be deployed. This runtime environment must offer well-defined function containers with well-defined interfaces to ensure that the implementation of a new function is open in terms of choice of supplier.

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Anders Johnsson is a senior research engineer at Vattenfall Research and Development AB. His professional experience includes power system monitoring and control with special focus on technical IT and communication. More recently, Johnsson has been working on IEC standardization projects. He earned his MSEE degree from the Royal Institute of Technology (Stockholm, Sweden). Contact: anders.johnsson@vattenfall.com

Jan-Erik Söderström is a senior engineer at Vattenfall Eldistribution AB. His professional engineering career started with system planning and asset management. For the past decade, Söderström has held several positions in the transmission and distribution sector in Sweden. Contact: jan-erik.soderstrom@vattenfall.com

Per Norberg is a senior adviser at Vattenfall Eldistribution AB. His professional engineering career started with system planning and asset management. For the past decade, Norberg has held several positions in the T&D sector in Sweden. As a CIGRÉ member, he has authored and co-authored a number of international power engineering articles. He is also an Adjunct Professor in Power Engineering at Chalmers University of Technology. Contact: per.norberg@vattenfall.com

Axel Fogelberg is an engineer with Gotlands Energi AB. For the past ten years, he has been engaged with the study of soft protection and control systems. Contact: axel.fogelberg@geab.vattenfall.se