MODERN CONTROL AND PROTECTION SYSTEM FOR HVDC

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1 Abstract

For High Voltage Direct Current (HVDC) applications, the control and protection system plays an essential role in the overall performance of the transmission system. The control and protection system adopted by ABB Power Systems uses the latest technology from the fields of electronics and microprocessors. The main objective of this paper is to describe the experience from using the MACH™ (Modular Advanced Control for HVDC) system with Base Design, from development, design, implementation and testing to commercial use. MACH is a fully computerized control and protection system. Base Design is the internal name of a complete well proven platform for the implementation of the control and protection system for an HVDC project, including the method of working of such a project.

2 Introduction

There has been rapid development in the areas of control and protection equipment for power system applications in recent years. This has been made possible mainly due to general electronic development, but also by introducing new methods of application programming. ABB Power Systems uses HiDraw, a fully graphical block programming language, and HiBug, a fully graphical debugger.

The main characteristics of the MACH are the high degree of functional integration and the open systems interface approach.

The open systems strategy is reflected both in the use of industrial standard serial and parallel communication buses, as well as in the use of standard formats for all collected data (such as events, alarms and disturbance data). This makes it possible to take advantage of the latest achievements in electronic engineering, thus ensuring timely development of more advanced functions and enhancement of performance for a long time to come.

Integrated with the MACH control and protection equipment is the Station Control and Monitoring (SCM) system. Work stations (PCs) are interconnected by an Ethernet local area network. The distributed system for remote I/O, for control as well as for process interfacing with the SCM system, is built up by a field bus network.

Converter control and protection principles are based on the well proven ABB HVDC control system that is now in operation in over 80 converters around the world.

The Base Design provides a complete well proven platform for the implementation of control and protection for an HVDC project. Experience from previous projects is fed back to ensure continuous improvement.

The first installation with the MACH system using the Base Design concept, the Skagerrak III project, a cable transmission between Norway and Denmark, was put into commercial operation in late 1993. This first installation proved extremely successful from the start, with no single forced outage caused by the control equipment during the first year of operation. By early 1996, another two installations relying on the MACH system had
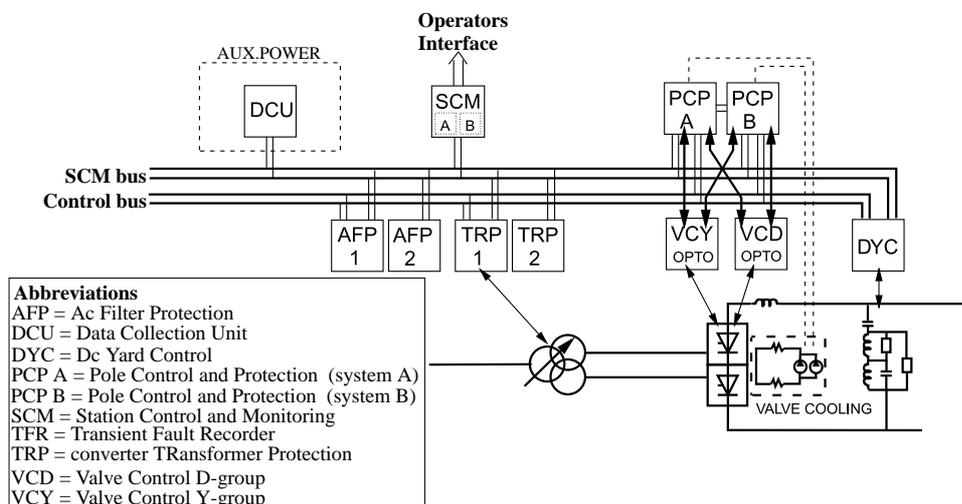

Fig. 1 Control and protection overview.

been handed over to customers, the Baltic Cable project between Sweden and Germany and the Kontek project between Denmark and Germany, both cable transmissions. Further, the Chandrapur-Padghe project in India and the Leyte-Luzon project in the Philippines are both under delivery. The Chandrapur-Padghe project is the first bipole line transmission using the MACH system.

3 Aspects on Design

3.1 The MACH System: General

As the MACH system is a control and protection system developed specifically for HVDC, many compromises have been avoided. The volume reductions in the hardware have been substantial, as illustrated in Fig. 2. The y-axis shows the number cubicles for a station-pole for a typical monopolar HVDC transmission. Fig. 2 also gives an indication how development and integration will proceed.
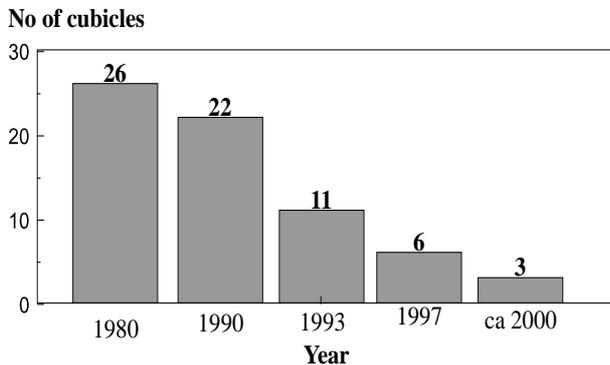
No of cubicles

Fig. 2 Cubicle reductions.

Each pole control and protection cubicle includes, in one framework, all controls; from the interstation telecommunication system and operator control interface to the converter firing control. A second framework houses a double set of DC protections. The system is built using state-of-the-art microprocessors and digital signal processors (DSPs), connected by high performance industry standard buses and fiberoptic communication links. The critical parts of the system are designed with inherent parallel redundancy, and use the same redundancy and switch over principles as used by ABB for HVDC applications since the early 80s. It is important to remember that because of the redundancy, maintenance of the control equipment does not require any shutdown of main circuit equipment.

3.2 Hardware

The HVDC control and protection system is built around a family of general usable circuit boards. The main control and protection system is based on MULTIBUS II units, which is an advanced 32 bit, processor independent open bus. For this bus, two general purpose single board computers, a high speed digital signal processor (DSP) and a complete firing control board for six valves have been designed. These boards are used for most control and protection functions of the HVDC system. The microprocessors on these boards are selected from the comprehensive ranges of the world leading manufacturers Intel and Motorola.

The circuit boards are designed to ensure the highest possible reliability and a minimum amount of maintenance. For example, this is achieved by the use of precision resistors to avoid adjustment potentiometers. Where potentiometers are still necessary they are mostly used in such a way that they can be factory set and do not need to be adjusted in the field.

Very short repair times are also facilitated by the internal self supervision. Another contributing factor to this, is the high degree of integration in all units.

3.3 Software Development Tools

A great deal of effort has been put into the development of software. Practically all functions within the control and protection system are built in software. A powerful software development and debugging tool is thus essential to be able to effectively produce high quality software. ABB Power Systems uses HiDraw, a fully graphical block programming language, and HiBug, a fully graphical debugger, both operating under Windows on networked industry standard PCs. HiDraw is very easy to use, and is based on the simple point, click and drag method. The user combines and connects symbols (blocks) from a symbol library to a schematic. HiDraw generates code from the schematic, either in a high level language (such as ANSI standard C, PL/M or FORTRAN) or in assembly language. Each single board computer in the MACH family has its own library of pre-defined and pre-assembled blocks. Functions which are not available in the symbol library can easily be defined and linked to a suitable schematic with a name reference. The generated FORTRAN code is used for direct input to electromagnetic transient studies in EMT-DC. In this way, a perfectly accurate model of the complete control system can also be used for digital studies.

One of the greatest advantages of HiDraw is that the printout of the drawn schematic provides the accurate documentation of the application software, i.e., the source code itself is in the form of a functional block diagram. Fig. 3 shows a HiDraw schematic of an AC system damping controller for an existing HVDC project.

To facilitate program debugging in the target system, a fully graphical debugger named HiBug is included in the HiDraw package. HiBug allows the user to view several pages in HiDraw schematic at the same time, and see any software signal in real time simply by double clicking on the line that represents the signal. Parameters can easily be changed by double clicking on the value and, via a dialogue box, printing in a new value. HiBug also facilitates single or multiple stepping of tasks and coordinated sampling of signals. The fact that HiBug allows user-friendly inspection while the application is up and running makes it an excellent maintenance tool as well.

3.4 Base Design

In parallel with the introduction of the MACH system, there was more focus on total quality and customer satisfaction. Extensive reuse of software and feedback of experience gained improves improves quality continuously. A software, hardware and general experience platform called the Base Design provides a complete system for control and protection. Customer focus is ensured through the high flexibility of the Base Design, which is designed for simple and fast adaption to customer requirements. The Base Design platform represents more than just equipment; it includes:
- hardware and software for control and protection
- documentation
- interfacing with the customer's equipment
- method of working; from system specification, design, implementation and testing to installation.

The HVDC control and protection system is a computer system with a certain percentage of new designs for each project, the amount mostly depending on special requirements from the customer. The total quality, in terms of commitments to the customers and performance after installation of such a system, is closely

Fig. 3 HiDraw schematic of an AC system damping controller.

related to the amount of new design. It is therefore important not to underestimate the amount of new design for a project, and consequently also the risks involved of such development. Base Design means, in simple terms, that whatever new functions are used for a previous project, are subject to extensive evaluation after the completion of the project. If experience is good, it can be incorporated in the Base Design either directly or as an option. As most of the software for a new project is already developed, debugged and delivered, through the Base Design platform, the amount of new design can be minimized and the special needs of the customer can instead be focused upon.

Fig. 4 shows the percentage of new software design for the recent HVDC projects, starting from the Skagerrak 3 project at 100%, for which the MACH system and the Base Design were introduced. The measured quantity is executable code. The rise in new design for the Chandrapur-Padghe project is mainly due to new design of bipole control functions and protections. The Chandrapur-Padghe project is the first bipolar transmission project using the MACH system. "New design" also includes the feedback from project to project which continuously improves the

Fig. 4 Percentage of new software design for recent HVDC projects.

Base Design. The figure above gives an indication of the relative amount of new design for a typical HVDC project.

3.5 Workflow

The design and testing of the control equipment comply with the quality standard ISO 9000. The principle of the workflow is shown in Fig. 5. In the DPS (Dynamic Performance Study) the pole control functions are tested against an analogue or a real-time digital HVDC simulator. The software released for the DPS is identical with the software in the system design stage, and revision orders are used from the start of the DPS. Functional tests or bench tests are made for control and protection functions using simplified simulators. The debugging is done at this stage.

Fig. 5 Control and protection - Workflow.

A comprehensive factory system test (FST), in which the complete control and protection equipment is assembled and connected to an HVDC simulator, is of great importance. The simulator arrangement is very detailed, and appears to the control system as the real power system, complete with generators, lines, converter valves, switchgear, etc. Experience from the FSTs is very positive. In particular, it has been proven possible to shorten the commissioning period and improve the quality of the de-

livery. During the FST the control and protection cubicles are energized and are continuously in operation for a couple of months. The following are included in the FST:
- greenlining of hardware connections
- verification of coordination of the control and protection actions
- verification of functions testing of which on site is not feasible.

4 Operator Interface

Integrated with the MACH control and protection equipment is the Station Control and Monitoring (SCM) system, a fully computerized and redundant system. The solution with operator workstations in local area networks (LAN) is very cost-effective, and is also in perfect agreement with the open systems interface strategy. Very high performance is achieved mainly because all data collection and ordering are implemented in software functions in distributed control units (DCUs) integrated into the control and protection system. These DCUs are single board computers from the MACH family.

Apart from the fully graphical man-machine interface (MMI), the system also provides easy access to all stored data (such as events lists and archived analogue data) as these are stored in standard formats readable by most database and spreadsheet software.

Separate gateway stations (GWS) can be added to the LAN to handle the interface with larger SCADA systems that are either remotely or locally placed.

5 Next Generation and Trends

Development in the field of electronics is extremely fast at present and the best way to ensure that designs can follow and benefit from this development is to build all systems based on open interfaces. As explained previously in this paper, this is done by continuing on the same path using international and industrial standards wherever possible as these types of standard have a long life and this also ensures that spare and enhancement parts are readily available.

Integration of functions will make further progress and the trend towards building the system on combinations of standard, general purpose computers and high speed digital signal processors (DSPs) will continue. As indicated in Fig. 2, developments in microprocessor capability and increased integration will result in cubicle reductions to roughly six per pole in 1997 and three per pole in 2000, including the full inherent redundancy. The software for the control and protection system will be inherited from the MACH system and the Base Design platform. This means that the software functions for control and protection used with the MACH system will be identical for the next generation of hardware.
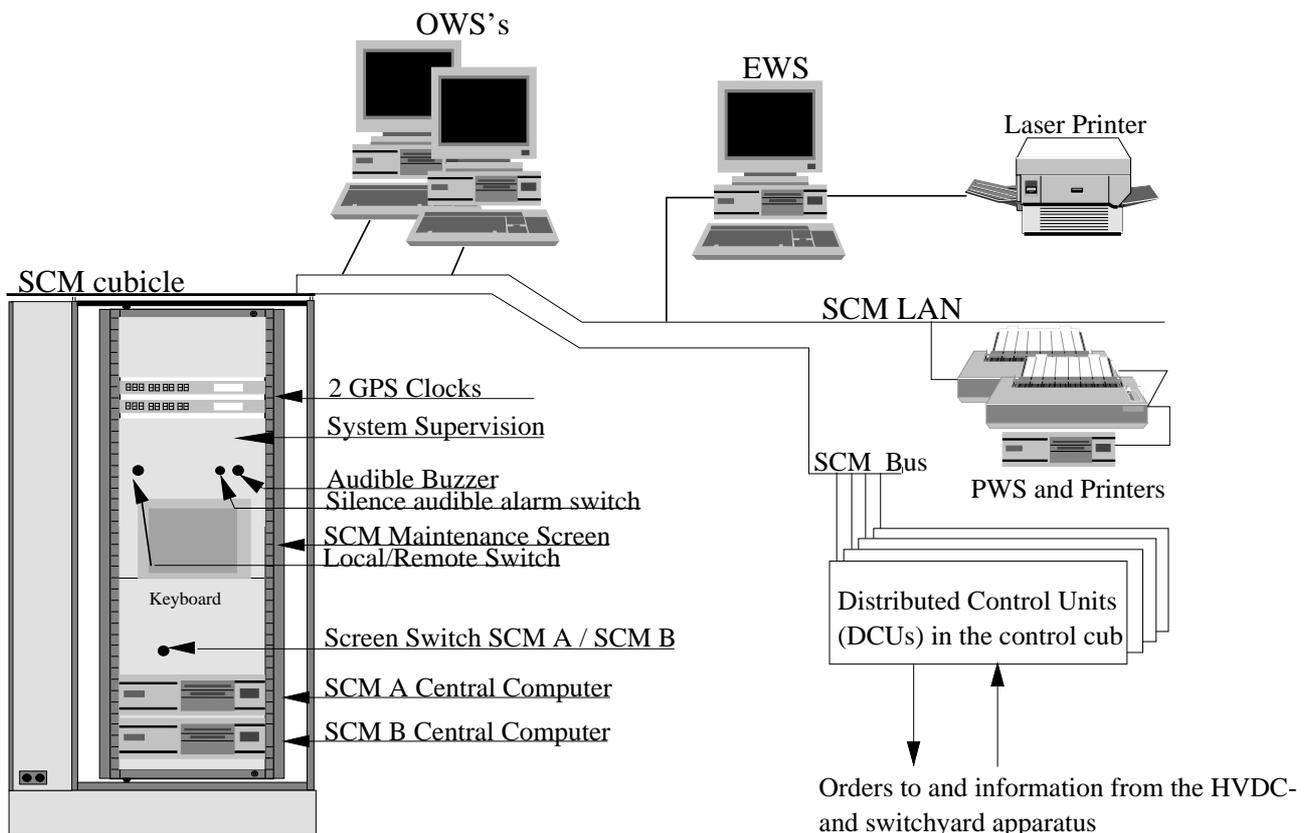

Fig. 6 Station control and monitoring system.

6 Experiences and Conclusions

This paper has outlined the experience gained from, and design aspects of, the fully computerized control and protection system MACH. The Base Design, which is a complete platform for the implementation of the control and protection system for an HVDC project is also introduced here.

Reviewing past results from installations using MACH system and the Base Design concept, one can establish that these have been a clear success. There has been a marked improvement in performance and quality. Before the introduction of the MACH system, the time schedule for the commissioning of an HVDC station was mainly determined by the installation and testing of the control and protection equipment. With the first installation of the MACH system, the Skagerrak III project, the time from the shipping of the control equipment from the factory to commercial operation of the HVDC link, was three months only. The Skagerrak III link had no single forced outages caused by the control equipment during the first year of operation. To this date, six converters using the MACH system are in commercial operation, and another six are under delivery.

There has been substantial integration of functions and reduction of cubicles, and the trend towards further integration will continue. The open systems interface strategy, which reflects the use of industrial standards to the extent this is possible, will remain an important principle.