CONCEPT FOR A HIGHLY SOPHISTICATED GENERATION OF PROTECTION AND CONTROL DEVICES
UTILITIES' REQUIREMENTS AND EXPERIENCE

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SUMMARY

This contribution describes a new concept in the design of protection and control devices on the basis of modern 32bit hardware components and modern object orientated software design and engineering technology. The main goal is user friendliness, high availability, dependability and cost effectiveness.
The users requirements for modern protection and control products and their experience with numerical devices are reported.

INTRODUCTION

The advances in microelectronics of the 1970's led to the development of new protection concepts. The first numerical protection devices employing microprocessors in the implementation of protection functions arrived on the market in the early 1980's.

These first numerical protection devices were still using 8-bit microprocessors requiring analog preprocessing to overcome the limitations in computing capacity.

The availability of 16-bit microprocessors in the mid 1980's has made it possible to develop purely numerical protection devices digitizing the analog measured values early on and thus they don't actually require any analog preprocessing. The high number of integrated functions has, however, necessitated the development of multi-processor systems. Thus medium-voltage distance protection could be implemented with a single processor whereas very-high-voltage distance protection required up to 6 microprocessors.

Utilities' Experience

In EAM, a regional utility in Germany, 44% of all protection devices are numerical devices nowadays. Since 1994, the company deploys only numerical devices in distance protection. This device generation has been satisfactory throughout regarding commissioning, operation and event handling.

With the introduction of numerical protection devices, differing operating concepts and operating philosophies were encountered. This led to new findings requiring the technical staff to change their way of thinking.

The scope of parameters that may be set in the state-of-the-art devices is quite extensive. In order to fully program the system protection relays with the setting parameters, to read out the operating data and to process the data, the use of a PC is mandatory. Most parameters are, however, defined just once in a company's customized default setting. The local control panel integrated in the devices can only be recommended for the rapid changing of individual parameters during commissioning, for example, or for the readout of measured values and operating data by unskilled staff.

Whereas the generation of the analog electronic protection relays exhibited failure rates that could be quite serious requiring extensive retrofitting activities, the numerical devices are distinguished by a very low overall failure rate. The initial apprehension about a suspected higher malfunction rate caused by the extensive self-monitoring functions of the state-of-the-art devices has turned out to be unwarranted.

Technical Products Evolution

As part of the technical evolution, the first 32-bit microprocessors for industrial products became available in the mid 1990's. The principal characteristics are

- Low hardware costs (< 20 $)
- High density of a multitude of functions integrated on a single chip
  (↳ embedded controller)
- High reliability on the basis of decades of experience in the PC market
- Large batches readily available

Consequently, the application of these 32-bit microprocessors has produced an innovational thrust in substation protection and control technology. Considerable improvements in functional density, user friendliness and presentation are anticipated. The application of highly integrated modules will allow more compact designs.

SPECIFICATIONS FOR A NEW FAMILY OF BAY DEVICES

The developments on the PC market within the past ten years can serve as a guide to the trends that we may anticipate for the development of bay devices in substations. Based on an analysis of the past ten years, the following important trends emerge:

- Development of standardized modules and of standardized bus systems

- Development of a user-friendly, intuitive operating interface
- Standardized operating elements
- Reduction in the number of possible operating elements
- Development of cost-effective bay devices

The utilities are to be provided with a device that can be handled intuitively. Standardization of functions reduces the utilities' costs. Strategies for the reduction of the 'total costs of ownership' are central to the developmental effort.

Utilities' Requirement

Users expect to see the following basic characteristics in system protection technology:

- Products at considerably lower costs
- Optimum adaptation of hardware and software to the task in hand
- Customized simplified operation
- Inspection intervals as long as possible
- Low rate of malfunction

Under the pressure of deregulation, power supply industry has to operate within a new framework. The individual companies compete for customers. For continued success in the market place, companies have to strive towards further optimization of their internal procedures. Already today, this is leading to a fundamental change in the approach to procurement and operation in many companies.

This development will not spare system protection technology. The measures applied to system protection technology in the past with regard to functionality and reliability at comparatively high total costs will change in the future.

The scope of hardware and software will have to be more specifically adapted to the individual application and task. In substations at low and medium system level, compact relays with reduced functionality and specifically adapted to the needs of medium-voltage technology will increasingly be used. In load-center substations, relays with a functional scope appropriate to the importance of the station will be used.

Assuming that users particularly in the medium-voltage sector will increasingly demand complete ready-made substations, the introduction of integrated bay control and protection devices (one-box solutions for protection and control) will gain in importance. At the same time, the first steps into this technology can lead to a higher level of bay integration. Eventually, a complete ready-made medium-voltage bay with integrated protection and control technology should be available as a standard. Thereby the user's workload is reduced with regard to important tasks in planning and design, documentation, wiring and installation of the substation.

One-box solutions for protection and control can take on further tasks in the future as, for example, monitoring and impart additional intelligence to the bay (interlocking functions, automatic actions, etc.)

In the age of office communication with the help of products such as Microsoft Word or Excel etc., the user expects ever more powerful software tools for administration and archiving of the setting, testing, signaling and fault acquisition data. As a matter of course, the Windows look and feel in user-friendly display, editing and documentation of the stored data will be expected.

In order to make the best use of the staff capacities that will be available in the future, inspection intervals should be further increased. This will be an additional contribution to the reduction of the specific inspection costs of the substation.

Specifications

The demand for cost-effective bay devices can be met by way of developing single-microprocessor systems. A high-performance microprocessor is needed to process all protection, communication and control functions in real time ('one for all'). Real time is understood as referred to a trip command issued by a protection function.

Microprocessor structure and programming need to cover a wide range of functions:

- Communication (IEC 870-5-103, Ethernet, ModBus, ProfiBus, K-Bus, Scada, ...)
- Protection functions [DTOC or IDMT (definite-time or inverse-time overcurrent protection), distance protection, ...]
- Control functions (interlocking, counting, ...)
- **H**uman-**M**achine-**I**nterface (intuitive user interface)
- Optional ancillary functions (voltage quality, highly accurate fault localization, ...)

The application of 32-bit microprocessors as used in modern PC's can build on proven success in the following areas:

- Very high flexibility with regard to application software ranging from CAD via DTP to office applications
- Re-usability of application software through downward compatibility
- Over 30 years of experience in worldwide application in several million units
- High future innovation potential through a mass market of millions of units sold

Additionally, there is a guaranteed flexibility that allows adaptation of the memory capacities for user data (RAM) and program code (ROM) to the prevailing market conditions. There is considerable scope for the integration of additional modules in the I/O area.

Hardware Design

The microprocessor forms the only active information node in a single-microprocessor system; it acquires data of peripheral modules, processes these data and sends data to peripheral modules. It controls the entire data transfer in the bay device. All other modules are passive from the information technology point-of-view, even if they have a microprocessor of their own. Access conflicts on the data bus are eliminated. This concept provides the basis for the design of a straightforward, passive bus system. Active elements such as a bus controller or bus arbiter are obviated. This way, the bus system is readily expanded. The recognition of fitted modules ('plug & protect') by the central microprocessor is feasible. The passive bus system concept achieves a considerable enhancement in reliability and safety compared to existing devices.

System Design

The design of the device software must also meet the specifications for a modern device family. The global specifications are as follows:

- Standardized **H**uman-**M**achine-**I**nterface for all bay devices
- Standardized communication software
- Application of a rule-based data model as description of all device functions
- Re-usability of device function software

Figure 1 presents the system design. The starting point is a data base system. Each function is stored within a function group. The software engineer defines a device by selecting function groups from those already defined. New function groups are added and are then available for application in further bay units.

The operator-machine interface and the communication software operate according to well defined rules. In the interest of rule-based software, the data model is evaluated quasi-'on-line' by both software components during run time. The presentation of the display text on the LCD or the structure and contents of the communication telegrams 'on-line', for example, are generated on the basis of the data model.

Protection and control functions are generated from a pool of existing software modules. New functions are integrated into this pool. Multiple application of individual functions is possible without any problems. The user can rely on identical characteristics of the same functions even if they are part of differing bay devices.

The operating program as a 32-bit application operates as a rule-based system just as the operator-machine interface. After uploading the data model, the device can be operated immediately. Logistic problems are eliminated since the complete data model is stored in the program memory of the bay device.

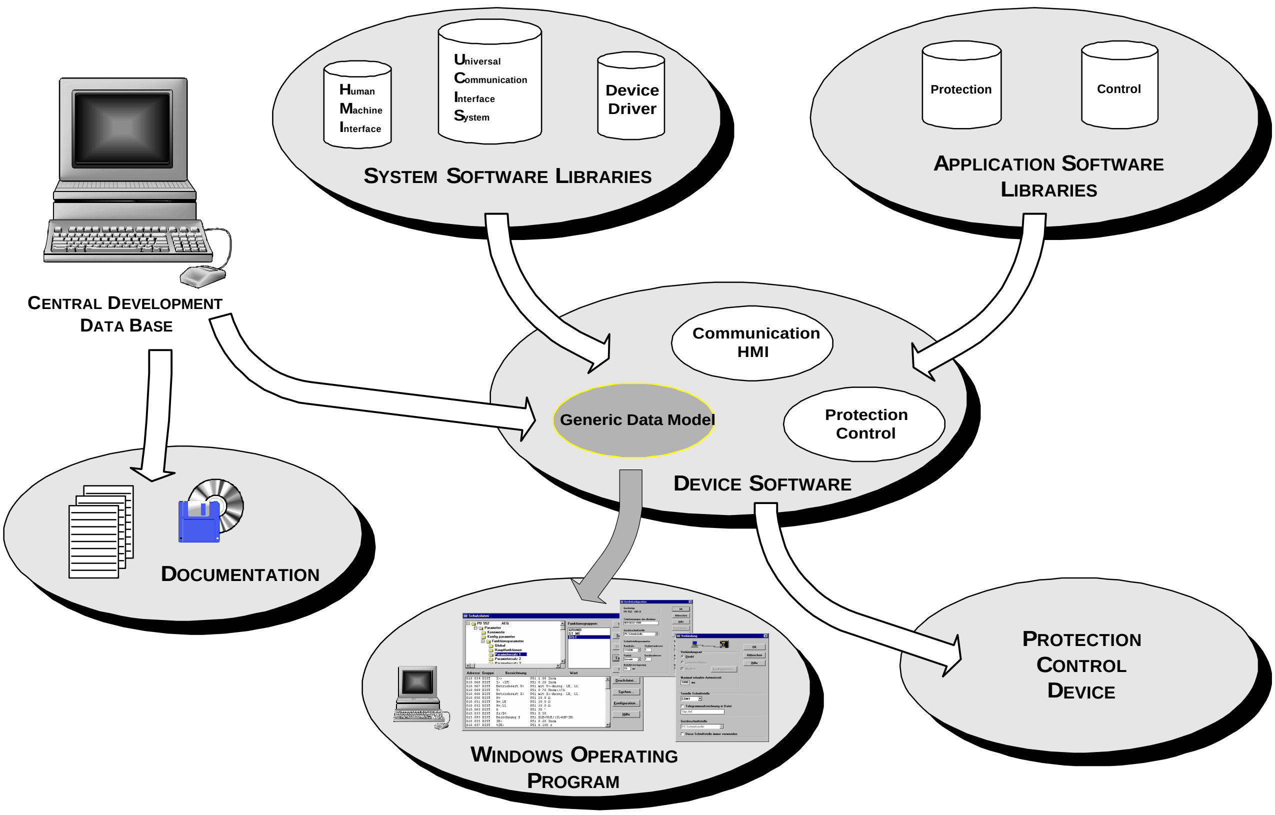

Figure 1: System design

MODULAR HARDWARE SYSTEM

Figure 2 shows the structure of the modular hardware system:

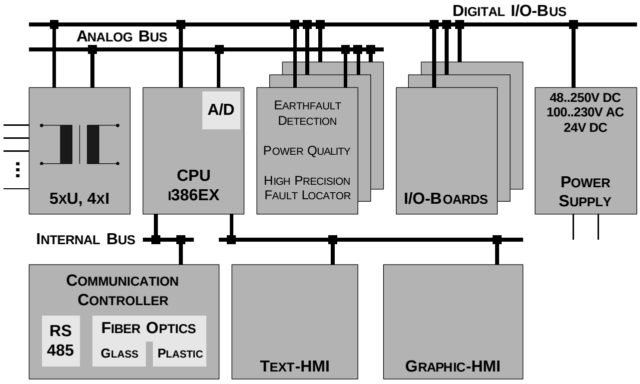

Figure 2: Modular Hardware System
(HMI: Human-Machine Interface)

The 32-bit CPU on the main board controls the digital I/O bus, the internal bus of the main board and the analog/digital conversion. The analog signals are passed on a dedicated passive bus from the converter modules to the modules requiring analog input signals. Since the data flow via the digital I/O bus to the main board is controlled, an expansion with I/O modules or ancillary modules for functions such as ground fault determination or voltage quality is readily achieved.

An additional communication module allows coupling to higher level control technology systems with differing protocols such as IEC 870-5-103/101 or Modbus. There is no load on the digital I/O bus.

MODULAR SOFTWARE SYSTEM

Figure 3 shows the modular software system:

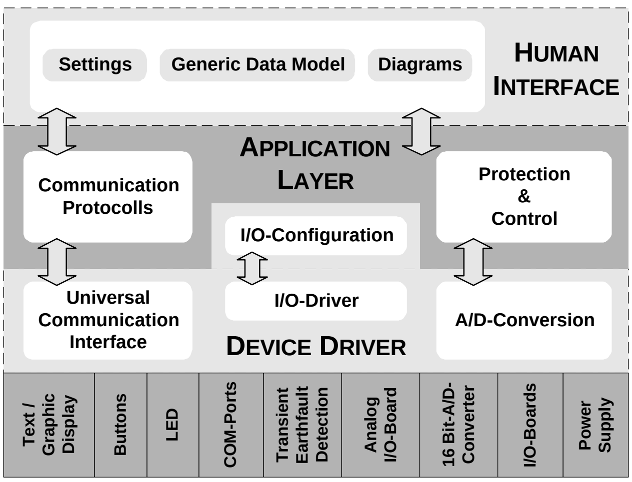

Figure 3: Modular Software System

The user functions of bay devices are implemented in software. The interaction between the individual software modules must be carefully tuned so as to ensure adequate computing times for all functions. The data interface between the individual software modules must be defined such that module B does not interfere with the data of module A. The method of object-oriented software designs makes it possible to encapsulate data areas of one module for separation from the other modules. Modern development tools support the technology of data encapsulation already during programming. Additionally, it is possible to define precisely which software modules exchange data and which do not.

With the consequent application of object-oriented software design, it is possible to increase the density of functions implemented in a bay device considerably without compromising the reliability and quality of the software.

Looking at figure 3, it is clear that, for example, only those software modules that implement protection and/or control functions have access to the A/D converters. Access to the serial interfaces is prevented. The level of the function software modules is also known as application layer.

Access to the modules is via the ‘device driver’ in the hardware application layer. Since the module can exchange data with other software areas via a single interface only, this data exchange can readily be monitored and controlled. Non-permitted access to data can readily be prevented centrally. A further advantage is gained with respect to type testing the device driver. Type testing can be carried out independently of the functions implemented in the bay device. Since the data interface is precisely defined and non-permitted access is prevented by the object-oriented software design, a complete test is possible.

The device driver example illustrates the improvement in the reliability and quality of device software achievable with modern methods and tools in software development.

EXAMPLE: ONE-BOX SOLUTION FOR DISTANCE PROTECTION AND CONTROL

The example of a distance protection and control unit will serve to illustrate the advantages of the concept of modular hardware modules and software modules.

To begin with, let’s define the device specifications. The one-box solution shall encompass the following three components:

- System functions with operator-machine interface and communication
- Bay-related control functions with bay interlocking

Protection functions of medium-voltage distance protection

As a first step, a device group is generated within the data base system. All required functions will be copied into this device group. All function groups stored for other devices in the data base can serve as source for copying into the new device group. In our example, we could use the device group of medium-voltage distance protection as our basis. The function groups for the control functions are taken from the device group of the existing overcurrent protection and control unit. The result is the data model for the new one-box solution with all required addresses.

In a second step all necessary software modules are combined. Protection and control modules are added from the software libraries to the system software (operator-machine interface, communication, ...) After this step, the device software can be generated.

The procedure for hardware definition is similar. Around 80% of the hardware modules are automatically defined: processor module, communication module, converter module, power supply module. Now the I/O area can be flexibly defined using the available components such as the protection I/O module, the control I/O module, the analog I/O module, the motor protection I/O module or the transient ground fault evaluation module. It is necessary to define which module in which slot should be supported by the device software. Since the required device driver and addresses are already contained within the device software, it is merely necessary to anchor the module-to-slot assignment in a device-specific software module.

After assembling the device hardware and downloading the device software, the device can be commissioned. Should the existing hardware and software modules not cover all the specifications then the required new components will have to be developed and will subsequently be integrated into the pool of available hardware and software modules of the device family. These new components will thus be automatically available for the definition of the next device.

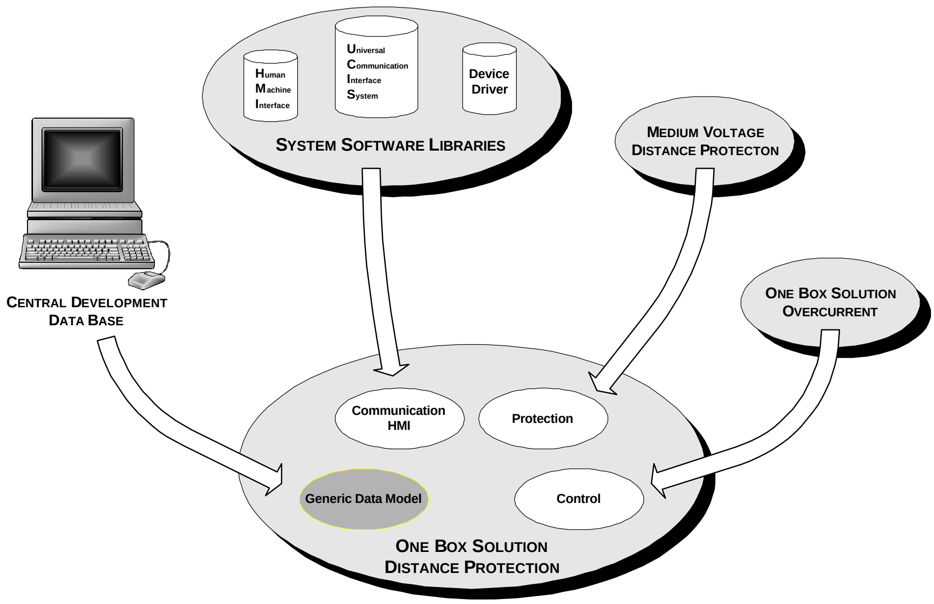

Figure 4: Design of a new product

CONCLUSIONS

This contribution demonstrates that it is possible to realize the goal of modular and re-usable hardware and software by the application of modern microprocessor technology and modern software design methods. The degree of standardization is 100% for hardware and around 90% for software. This concept has clear advantages for both users and manufacturers. The manufacturer can optimize production and hardware costs with larger batches and can implement more efficient production strategies. The high software development costs can be redeemed sooner by multiple application.

The advantage for the utilities is the considerable decrease in total costs. The ‘total cost of ownership’, that is the costs for purchasing, training and maintenance decrease considerably since around 90% of the device functions and 100% of the hardware modules are identical. Stock-keeping costs for spare devices and spare hardware modules can be reduced and decisions on the application of new devices can be arrived at more quickly.

In the utilities’ experience, numerical protection devices have proved satisfactory throughout. The extent of the parameters that can be set in the device is quite considerable but can be handled with the help of a customized default settings file and a PC.

In the future environment of the deregulated energy market, it is important to use cost-effective products adapted to the task in hand. From this point of view, the application of integrated bay control and protection units with an extended range of functions including monitoring and bay-related intelligence is of interest.

Among the goals will need to be a clear reduction of the manufacturing and operating costs.