PREPARATIONS FOR

THE

VIRTUAL RELAY SYSTEM

MBS 1000

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ABSTRACT

This MSc thesis describes the *preparations* for a new virtual relay system MBS 1000 (**M**ega **B**ase **S**ystem **1000**). The relay system has been developed to replace the present RED 500 relay system at ABB Oy, Distribution Automation. This represents a new type of relay system controlling and recording cases and events in the electrical network and cable system with *two* new dimensions. MBS 1000 represents the next generation of relay system of ABB Oy, Distribution Automation.

ABSTRAKT

Detta dokument är ett Filosofie Magister examensarbete som beskriver *förberedelser* till ett nytt virtuellt reläsystem, MBS 1000 (**M**ega **B**ase **S**ystem **1000**). Reläsystemet utvecklades för att ersätta det nuvarande RED 500-reläsystemet vid ABB Oy, Distribution Automation. Detta representerar en ny typ av reläsystem som kontrollerar och registrerar förlopp och händelser på elnät och ledningssystem med *två* nya dimensioner. MBS 1000 representerar en kommande generation av reläsystem från ABB Oy, Distribution Automation.

TIIVISTELMÄ

Tämä dokumentti on Filosofian Maisterin päättötyö joka kertoo *esivalmisteluista* uudelle virtuaali relesysteemille, MBS 1000 (**M**ega **B**ase **S**ystem **1000**). Tämä relesysteemi korvaa nykyaikaista RED 500 relesysteemiä ABB Oy, Sähkönjakeluautomaatiossa. Tämä edustaa uudenlaisen tyypin relesysteemiä joka ohjaa ja rekisteröi kulumisia ja tapahtumia sähkö- ja johtoverkolla *kahdella* uusilla ulottuvuuksilla. MBS 1000 edustaa tulevan sukupolven relesysteemiä ABB Oy, Sähkönjakeluautomaatiossa.

FOREWORD

In late 1995, Jarmo Saaranen, former profit center manager of ABB Transmit Oy, gave me the task to plan, define, specify, give possible solutions, suggestions and progress for a new relay system, including documentation for both hardware and software levels.

This work was originally written for ABB Transmit Oy in Vasa, Finland, mainly during the period from 01 February 1996 to 31 December 1998. In January 2001, this document was approved as my MSc thesis at the university of Åbo Akademi in Åbo, Finland. During the period from 1 January 2001 to 14 April 2004, some parts were added to the work.

My supervisor at Åbo Akademi was professor Joakim von Wright. I am grateful to him for his encouragement, valuable comments and his help and guidance in this work. I am grateful to my supervisor at ABB Oy, Distribution Automation, and the former Research Manager Tapio Hakola, for giving me the chance to continue this work that resulted in this thesis.

My thanks also to Jarmo Saaranen for his support at the beginning of the project, for making it possible for me to start the MBS 1000 project, Carl-Göran Österbacka (for his important ideas concerning the need for virtual dimensions), Henrik Sundell (for good pictures and basic comparisons of relays), Grels Linqvist, (for definitions, information, estimation of priorities and some points considering functions), Lars Nåhls and Janne Altonen (for explanation of functions and abbreviations), Pertti J Lehtonen, Ari Fagerroos, Max Enegren, Sture Still and the whole ABB Oy, Distribution Automation, for their support.

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CONTENTS

1. INTRODUCTION

In late 1995 thoughts came up to create a new hardware-software *super-system*, with attributes fulfilling demands far beyond the demands of ABB Transmit Oy's international relay and electrical distribution control system market, including functionality that competitors started offering after the turn of the century.

The system got the platform name **MBS 1000.** The **M**ega **B**ase **S**ystem **1000** provides service to surrounding units faster than ever before. The name is based on the fact that this system aims at offering a safe relay system fulfilling the demands on the future ABB Oy, Distribution Automation's (later ABB) market for many years to come. A data flow control revolution with a new way of thinking has been initiated.

Mats BJÖRKQVIST, EUR ING employed by ABB, Vaasa, Finland was appointed project manager of the MBS 1000 relay system.

Bolded style is used in the thesis to replace numerical or bulleted lists, emphasize winners in the tables (possibly of a special feature), draw the reader's attention on specific features or details and improve readability. Italic style is used to stress important system features, system extensions and improvements, and create system describing words and expressions.

1.1 INTERESTING ATTRIBUTES IN THE MBS 1000 RELAY SYSTEM

New interesting dimensions of the MBS 1000 relay system complement the former RED 500 relay system among other things the **loadability of the hardware kernels** and **core virtual data/code/configuration** of the relay(s).

The loading feature of the hardware kernels considers the old relays' large number of circuits that took care of a number of inputs, outputs, conventional logics, analog channels, the hardware that replaces the former software executed by the processor, and the processor kernel. These elements are to be integrated into one or several large/larger FPGA or ASIC circuit(s).

With the loadable feature regarding both hardware and software code, the MBS 1000 system adds new dimensions to the relay technology. The local user is able to update his own relay system by loading the new code elements into the relay. Thus, the system offers the developers and, ultimately, also the users of the relay families a fully dynamic concept considering both hardware and software development.

The MBS 1000 system implements a large amount of *hardware* in one or several ASIC or FPGA circuit(s). The former RED 500 relay family did not have these features.

ABB's research and development of relay families in the 90s awaked thoughts of demands for specifications that handle complex problems while the system has to be able to control the network and flow of energy under various conditions. Figure 1 shows the results of the development of different kinds of relays during the 80s and the 90s.

Figure 1. Generations of earlier relay systems [5]

The new ASIC or FPGA technology pushes industry a safe step forward in minimising the risks of hardware copying.

Another advantage is that this technology allows ABB to create small system boards including all the necessary hardware (and software) at a lower price. New solutions can be created based on the same, “freer” design, without having to start from the basics.

Here we leave the static level of the hardware that forces hardware designers to start a new design cycle whenever a small change has to be done to the hardware.

Some software that was earlier executed by a processor can now be executed by the hardware. Software programs are executed in the FPGA(s) or ASIC(s) units of the relay and not only by a processor kernel.

Also, we are able to speed up the slowest operations e.g. multiplication or filter calculation, when the hardware takes care of it (instead of a large number of cycles needed by the processor). The complex calculations are transferred from the processors to specially designed hardware performing the same calculation in a faster and more powerful calculation unit.

The aim is to improve the existing control, monitoring and electronic part of a typical control system by *replacing almost all of the basic hardware elements with ASIC or FPGA solution(s) allowing free configuration of both hardware and software of the system. Smaller sizes, reduced costs and faster operations are hoped for.*

The relays’ core virtual data/code/configuration dimension speeds up the system by using smaller RAMs with short access times and high system performance. When the relay needs e.g. new settings or codes or when the relay or system generates a “cache miss” situation, the required parts (both on software & hardware level) are now loaded into the respective targets of the concerned circuit(s) or data/code memory. Only some basic level SW and HW will be static in the target unit.

The aim is to improve an existing control and monitoring system by virtual loading of the needed software and hardware *from external data-code-function-control-configuration banks, when required.*

1.2 ORGANISATION OF THIS THESIS

This thesis is divided into two parts, *Preparations for the virtual relay system MBS 1000* (the open part of this thesis) and the separate appendix 5 of this thesis, *System descriptions for the virtual relay system MBS 1000* (the closed part of this thesis).

Part 1 consists of 5 chapters and describes important *preparations* for creating a new relay system.

In **chapter 1**, I introduce the purpose of this thesis and the basic new features of the whole system. I also explain how this part of the thesis is organised.

In **chapter 2**, I deal with the background and the tasks of a relay, the history of the SPACOM and RED 500 era and the structure and characteristics of these relay families. I end with a discussion about the reason for creating a new relay system.

In **chapter 3** comparisons and analyses are in focus. A number of relay families with main types and subtypes are compared in terms of the common protection functions offered by different relay manufacturers.

Chapter 4 contains general information about the MBS 1000 relay and the differences between the RED 500 and the MBS 1000 system. It also presents the different families of the MBS 1000 system and their basic attributes. In addition, I give some information for the design process during the design and planning phase of the MBS 1000 relay system.

In the last **chapter 5**, I present some results of the thesis.

2 BACKGROUND

In the middle of the 90s, thoughts came up to create a new relay system that is more flexible and more compatible not only with our own relays but also with the competitors' products. In addition, the hardware must be configurable and the relay system's software and hardware virtually available. These two new dimensions had to be added.

2.1 ELECTRICITY CONSUMERS AND NETWORK CONTROL

Almost all of us are consumers of electricity. When we wake up in the morning many of us probably start with a coffee. To make this coffee we need electricity. When we come to work some of us start the PC, for instance, to write, a report of yesterday's meeting.

The electricity needed for our electrical appliances at home or at work is received from the *electrical network* starting from the power station or power plant and ending up in, say, our PC, where we are the electricity consumer.

Between the power station and the consumer there is protection and control equipment supervising the flow of energy in the network. This equipment takes care of disturbances occurring in the energy transferred to us constantly through the electric network. This equipment is called a *protection relay*.

Protection relays are placed at certain locations e.g. to provide the distribution companies with information about the network. Protection relays (later called *relays*) usually react independently and automatically on events or failures in the network, but they can also be operated manually. Depending on the relay's design for general or more specific applications it is possible to supervise, safely transfer energy, measure different quantities and obtain the most important information about the system (network) [2].

Usually the relay measures voltages and currents in medium (20 kV) voltage networks. In addition, it samples, manipulates, records, controls and makes decisions based on measured data and changing of magnitudes during a specific time.

The relay product range covers a variety of relays for different protection tasks and services in the power distribution networks [2]. Indeed, there are *conventional output relays* included in the protection relay, but these are working as ending connectors e.g. connected to the charging motor of a disconnector.

ABB's *relay* offers a multifunctional, highly integrated microprocessor system with measurement, recording, control functions and decision making capabilities. *Relays are used to supervise power distribution networks.*

Supervision is based on measuring voltages or currents, for example, on the power lines [1].

2.2 MORE SPECIFIC TASKS OF THE RELAY

If a relay detects a fault on a certain line it activates the built-in conventional output relay(s) to eliminate this fault. These built-in relays can be connected and configured to control a device (e.g. a motor charging the disconnector) that disconnects the faulty power line from the network. Furthermore, relays are able to communicate with each other and forward error and status messages. These error messages may prevent further damage to sub networks that are connected to the power line that caused the fault.

A relay includes different functions and services, which can be divided into 8 main groups (based on the SPACOM relay family).

The first function group takes care of the user's need to set and configure the relay in different ways e.g. the delay time before the *conventional output relay* in the relay is to be activated after the unit has measured currents that exceed a preset limit. These functions form the **Control functions** group.

A relay basically measures voltages and/or currents on a target object e.g. in an electrical cable. Voltage and current transformers convert the high voltages and currents in the network line (using special constants) to mathematical values that the relay can handle in its A/D converters. Further, these currents and voltages are converted into values (hexadecimal values) that can be processed by a processor. By combining these constants into read values (including filtering) we obtain the results of the measurements as real mathematical values.

These values are used by the processor of the relay for computing and taking care of the second group of functions that include analysis of the measured inputs and making decisions based on the measured values. These functions form the **Protection functions** group.

There are many ways of implementing measurements in the relays, with or without electrical or mathematical filtering of the inputs connected to the objects (electric lines) connected to the relay. These different functions form the **Measurements function** group.

During the operation of the relay different kinds of situations may arise. The relay includes functions that record faults and events related to the network (e.g. communication), allowing the user to trace them afterwards. These functions form the **Post-fault Analysis function** group.

The relay continuously monitors the condition and the "quality" of its own functionality. The self-supervision system of the relay supervises the operation of the relay and external systems connected to the relay, recording faults and events. For these needs there is a group of functions called the **Monitoring function** group.

To be able to forward information from a local relay to a control centre some kind of communication is required between the relay and the control centre. The communication functions of the relays take care of the communication and the protocol of the communication interface. These functions which include the procedures and functions needed for the communication between the relay, other relays and the control centre form the **Communications function** group.

The user must be able to communicate with the relay and "understand" e.g. how the relay is configured. The relay can be controlled over a serial interface or through a user interface. Functions and procedures taking care of functions closely connected to the user and the user's communication with the relay are handled by the **User Interface function** group.

During testing and operation of the relay, tools are needed for diagnosing faults, settings, controlling and debugging the relay. These tools, called **Software Support functions**, are external and usually connected to the relay via some of its communication buses.

2.3 STRUCTURE OF A POWER DISTRIBUTION NETWORK AND THE RELAY'S LOCATION IN THE NETWORK

To control the relay system of the distribution network a control centre is required. This is located at the highest level of the network hierarchy. The control centre is connected to a group of relays and has an overview over the whole network.

Implementing network control and protection in this way decreases the expenditure of the communication between the devices and so the necessary data is always available where it is needed. Only data that are requested [my comments], necessary, of priority or interest to the higher level of supervision are passed forward [1].

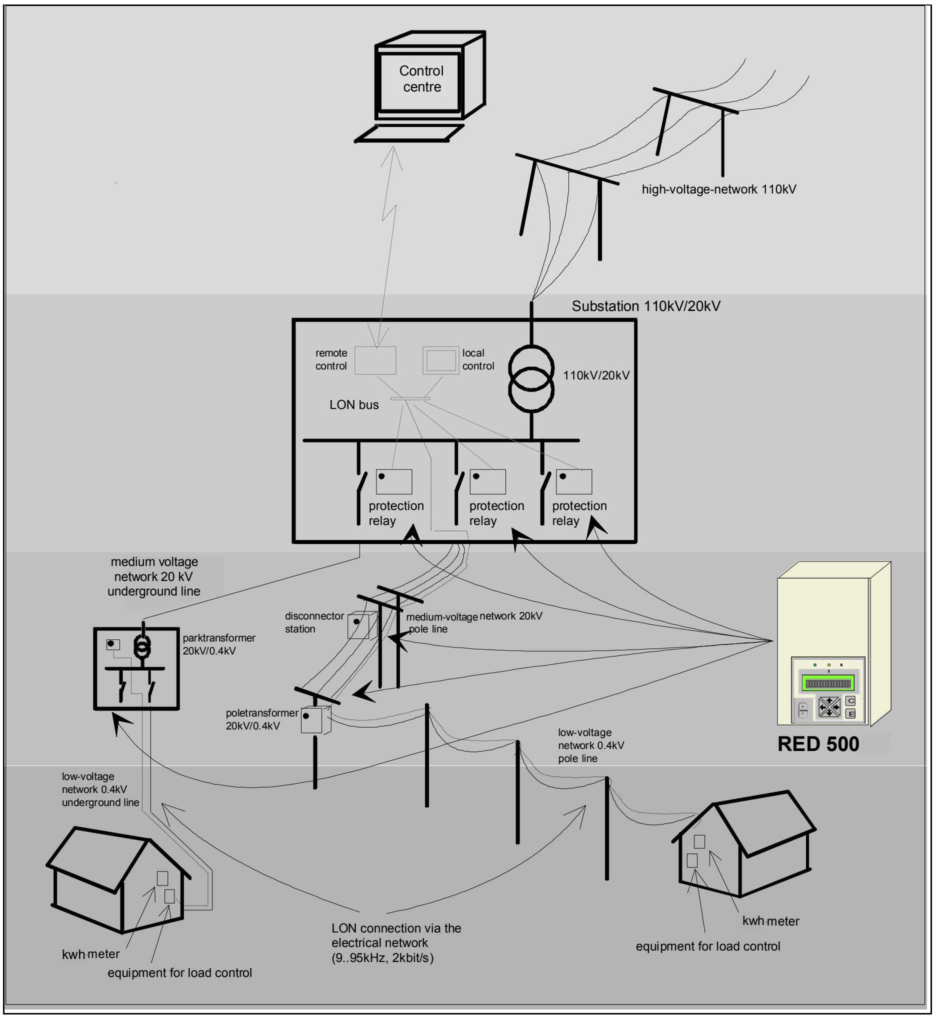

Figure 2. Typical location of a relay [2]

Figure 2 illustrates where a relay can be placed and where other systems are found. The different shadings indicate the different levels.

The **first** level and the lowest level is the user level (deepest grey). This level includes energy consumers. The consumers are connected to the next upper level through the 3-phase network.

The **second** level represents the 20 kV network. This is where the relays usually are located. This level is also the focus of ABB's production range. This level can include many different types of relays which take care of their own specific functions. The different types of relays usually include different functions (some of which are grouped).

Relays measure voltages and currents. To be able to react, if for instance a tree falling over the line generates an earth fault, and a set limit value is exceeded, the relay activates the motors of the disconnector between two transformers. The disconnector is opened and interrupts the current flow of the line. The disconnector can be operated automatically, manually or by remote control from the control centre (the control centre in Figure 2).

The **third** level is the substation level, where the 20 kV network is transformed to the 110 kV network. Here relays usually control the voltages and currents. The disconnectors are mainly operated automatically or remotely from the control centre. However, some of the disconnectors can also be operated manually.

The **fourth** level represents the high-voltage transmission network at 110 kV or, in some cases, 400 kV. At this level you also find the "highest intelligence" of the electrical network i.e. the control centre from where all sections of the actual network are controlled. This control centre is usually manned.

2.4 THE SPACOM ERA

The **SPACOM** era started in 1982 when the first relay to include a microprocessor supervising the 3-phase network appeared on the market. The **SPA bus** that was introduced in 1985 allowed remote communication with the relays.

Initially, these relays provided much new information about the network's elements. The relays (representing slaves in the hierarchy) were often polled for status information by a unit (representing the master in the hierarchy) that handled the information.

The master received the commands and interpreted them. Depending on their contents, these messages alert the master of different events or actions to be taken.

Masters usually work as central units whereas slaves work as follow-up units implementing the basic functionality of the control system.

However, during the 80s, functions (including higher demands of the functionality) were added to the relays on both the hardware and the software level to such an extent that the processor's capacity reached the maximum limit.

Due to slow communication buses with one master unit polling many relays (slaves) for status information, the real time of the status of the system slaves suffered from a kind of “inflation”, that is, when the data arrived it was already old.

SPACOM relays use the SPA bus. The communication on the SPA bus is an ASCII type of communication that, in principal, starts with the “>” character when messages are transmitted. Messages received from a unit starts with the “<” character.

However, the SPA bus was too slow to handle time dependent and time critical status of certain relays in certain situations where many relays were connected together and configured to work as a “team”.

Figure 3 illustrates the typical structure of a SPACOM relay. The SPACOM relay includes a *power unit* that supplies other modules with the current needed. The power unit is located in the same module as the conventional output relays (the *relay module*).

A typical relay includes current and voltage transformers connected to the network. Together these form the *current-voltage-transformer module*.

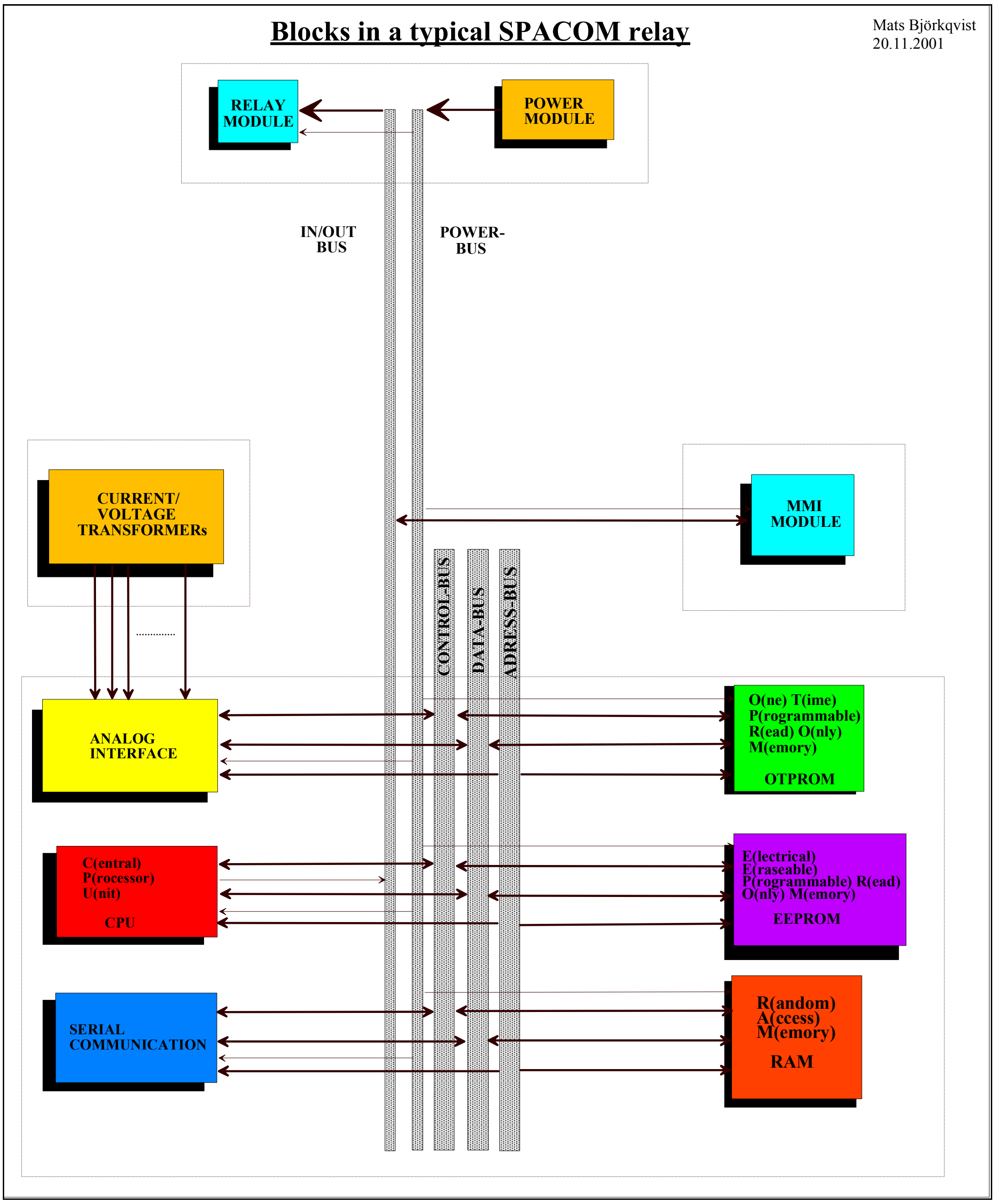

Figure 3. A typical logical structure of a SPACOM-relay.

To be able to configure the relay there is a *MMI module* (**M**an-**M**achine-**I**nterface module) on the front of the relay. The most complex unit is the module that processes data, makes decisions, controls the conventional output relays and other modules in the relay. This module incorporates the analog interface, the CPU, serial communication, OTPROM, EEPROM and the RAM.

Figure 4 presents the SPAJ 140 C relay, a typical relay of the SPACOM family.

Figure 4. A typical SPACOM relay [3].

2.5 THE RED 500 ERA

To meet the needs for creating a more competitive, new ABB relay family solution, the **RED 500** project under the COMSYS platform was started. It was important to make system units of the same subfamilies more compatible with each other and to create software compatibility for almost all relays based on this platform. This compatibility was more software-related.

Also, a more compact, plug-in type hardware solution was aimed at. Making just a few basic hardware packages that can be used for several applications and decreasing the huge number of relay variants produced during the SPACOM era led to reduced costs.

New features that were added to the relays were configuration/ application language, the multiprocessor system and the loadable of the software and configuration.

The RED 500 relay family is based on the RED 500 platform. Figure 5 shows the members (subfamilies) of the RED 500 platform. Relays of the RED 500/E subfamily are principally delivered with the same MMI (a non-graphic solution) as the relays of the RED 500 A/B/ and /C subfamilies.

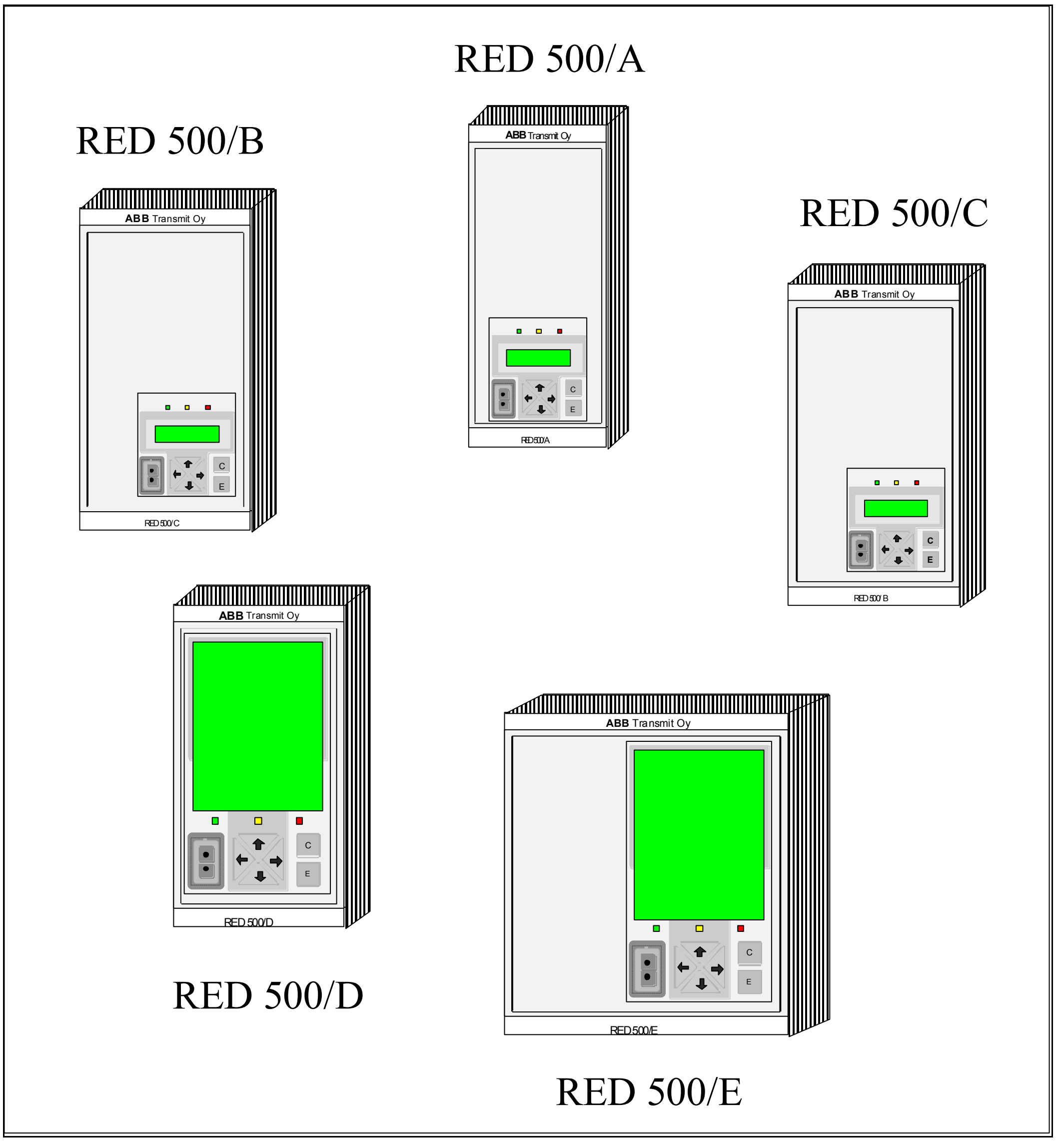

Figure 5. The five members (subfamilies) of the RED 500 family.

In addition, a software package including the necessary functions is easily chosen from a function library and included by linking the appropriate object files together.

Free object description used in the form of graphic setup services and communication through fast local/remote buses were added, as was multimaster communication working according to the philosophy - “the first that is on the bus gets it”.

One advantage of this platform is that several kinds of relays can be realised in a short time, because there is no need to redesign a whole new relay from scratch, since implemented and tested main blocks already are available in a design database.

The main function blocks included in the RED 500 system are:

- Protection
- Control
- Monitoring
- Measurements (A/D conversions)
- Post-fault Analysis
- Communication
- Software Support

- MMI User Interface
- MIMIC User Interface

- IN/OUT

Chapter 2.2. describes the first 7 function blocks. However, there have been some changes in the RED 500 system compared to the SPACOM relays. The *user interface* function blocks have been divided into two different sub function (MMI and MIMIC User Interface) blocks. These modules are also included in the relay structure as separate hardware circuit boards.

Further the former measurement and/or protection function blocks have been either separated or combined, resulting in a new function module taking care of the digital inputs and outputs (IN/OUT) (conventional output relays). These are designed as a separate hardware module located on a separate circuit board (not in the RED 500/A subfamily) beside the MCPU board in the relay.

These blocks of functions can be combined according to the type (but also demands) of relay the designer intends to construct. All members of the RED 500 family have some common characteristics and features which make them members of this family. All RED 500 relays have basically the same outlook and a uniform user interface. Some of the families include the same application objects and sub objects.

The RED 500 family is composed of five members originally called RED 500/A, RED 500/B, RED 500/C, RED 500/D and RED 500/E (refer to figure 5).

Figure 6. Member of one of the RED 500 family, RED 500/A [3]

Figure 6 shows the RED 500/A relay, which is the simplest member of the RED 500 relay family. The most complex member of the RED 500 family is the RED 500/E relay. This differs from the other members of the family as to functionality and price, because it can include the whole range of existing function blocks.

2.5.1 MAIN CHARACTERISTICS OF THE RED 500 FAMILY

The RED 500 family has a wide range of application objects. The relays differ from each other in complexity, functionality and price and thus it is easy for the customer to choose the required relay. In terms of functionality, the RED 500 relay can be divided into five levels.

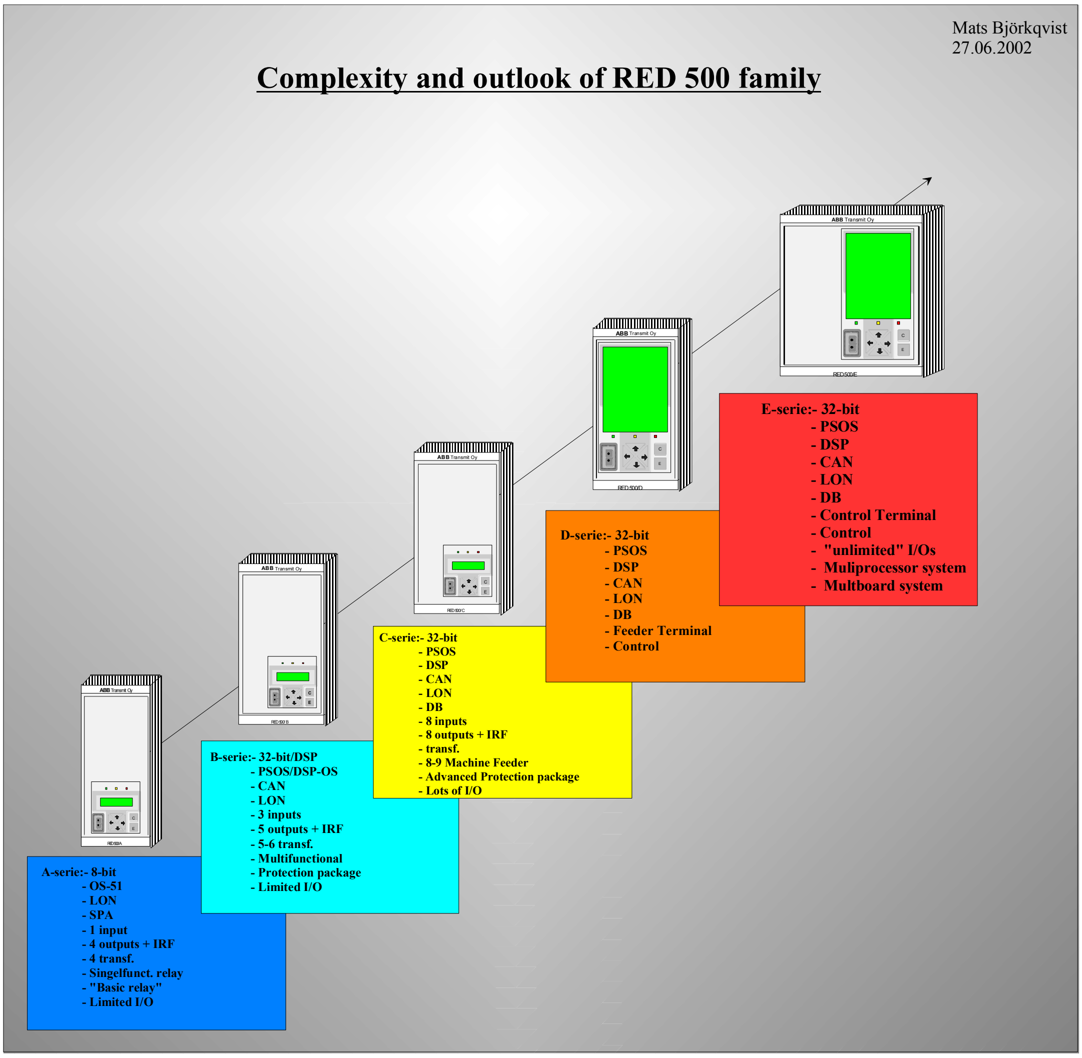

Figure 7. RED 500 family relays and their complexity.

Figure 7 shows the five members (subfamilies) of the RED 500 family. The RED 500/A subfamily to the left includes the simplest function relay with a small number of inputs and outputs. The most complex member is the RED 500/E subfamily that includes a lot of functions and a lot of inputs and outputs.

The relays of the RED 500 family can be connected together and communicate with each other.

2.5.1.1 RED 500/A RELAY SUBFAMILY

The RED 500/A series relays are a single-function relay that is a profitable “one card-solution” for all kinds of single function applications on the market.

Due to different configurations made on the parameter level for different kinds of functions and serving codes, the RED 500/A is easily adapted to specific applications. The same code takes care of the same (but also new) kind of functionality as the lower-end relays of the SPACOM family range (<SPAx 140) [1].

2.5.1.2 RED 500/B RELAY SUBFAMILY

So far, no relay of the RED 500/B subfamily has been launched, because this member of the RED 500 platform was under specification in 1998 (when this part was written). The RED 500/B subfamily will be more complex than the RED 500/A subfamily, with more programmable logical devices (PLD) and a higher number of analog input channels. The price of these relays will also be higher than that of RED 500/A relays.

This relay subfamily takes care of the higher-level function map of the SPACOM series, from SPAx 140 on and up to the lower end of the SPAx 300 family.

2.5.1.3 RED 500/C RELAY SUBFAMILY

The RED 500/C subfamily represents a group of relays with a more complex functionality than above mentioned relays. This family is strong in analysing data and compatible with RED 500/D and RED 500/E subfamilies. Function groups included in RED 500/C subfamily are:

- Protection
- Control
- Monitoring
- Measurements (A/D conversions)
- Post-fault Analysis
- Communication
- Software Support

- MMI User Interface
- MIMIC User Interface
- IN/OUT

The function blocks are described in chapter 2.2 and 2.5. Some additions made to these relays improve their capacity to calculate the read input values. These added features are:

- Part of the relay multiprocessor-driven
- Multifunctionality
- Low-cost solution
- One-card solution

During the development of the relay, the capacity of calculating the input analog values had to be improved. This is also the reason why these relays are partly multiprocessor-driven. This feature allows control functions to be taken care of by one processor, and calculation and part of the communication by other processors. The tasks of the relay are distributed among the processors to minimise the work of the separate processors.

Another need that came up was the possibility of loading new software into the relay. The same software was to be used in many different hardware versions of the same family. It was time to add the attribute multifunctionality to relay technology (in the meaning of one hardware for many functions). In addition, the RED 500/C range is a **low-cost**, **one-card solution**. The relays of this subfamily is code and (with some exceptions) hardware compatible with the higher-level subfamilies of the RED 500 family.

The RED 500/C subfamily is compatible with the RED 500/D and RED 500/E subfamilies as to design, service, setup and test flow. The subfamily takes care of the higher-end function map of the SPACOM series, starting from the lower part of the SPAx 300 family.

2.5.1.4 RED 500/D AND RED 500/E SUBFAMILIES

The RED 500/D and RED 500/E subfamilies represent the highest complexity and functionality of ABB’s relays.

These subfamilies include:

- Protection
- Control
- Monitoring
- Measurements (A/D conversions)
- Post-fault Analysis
- Communication
- Software Support
- MMI User Interface
- MIMIC User Interface
- IN/OUT
- Multiprocessor-driven
- Multifunctionality

Refer to the chapters 2.2, 2.5 and 2.5.1.3 for an explanation of the function blocks. The RED 500/D and RED 500/E subfamilies have attributes that other RED 500 subfamilies do not have. These relays are full-scale relays fulfilling every need the user may have.

Additional attributes are:

- Powerful protection
- Multicard solution
- Extensive control
- Complex functionality
- Expensive relay solution

Allowing many function blocks to be added to one relay and at the same time user-configurable functions, these relays offer a block-combining build-up of suitable protection functions.

Now the need for an economical solution has to give way to complex functionality, and an expensive relay solution that satisfies any needs the user may have is used. This results in a multicard solution with extensive control.

These solutions offer the user a relay with a great number of additional cards in the same relay unit and a large number of additional functions including functionality setups, configurations and services.

The only difference between the RED 500/D and RED 500/E subfamilies is that the E subfamily offers plenty of free space inside the relay for an almost unlimited number of IN/OUT cards. In some places a huge number of IN/OUT channels are needed and now the user can fulfil all his needs by using one single RED 500/E relay. Usually, the RED 500/E subfamily is provided with a MMI instead of the MIMIC interface.

These subfamilies have the same, or higher level of functionality as the SPAx 300 and SPAx 500 family of the SPACOM series, and are at a similar HW and SW level as SRIO 500/1000/2000.

2.5.2 TYPICAL BLOCKS IN A RED 500 RELAY

The high-end relays of the RED 500 family usually include a multiprocessor system. In many relays today the focus has been on a higher data processing throughput. In these solutions, communication, calculation and data-manipulation functions are sometimes handled by several processors.

Figure 8 illustrates the block scheme of a typical relay of the RED 500 series. The block scheme includes the ***MAIN CPU*** that takes care of system supervision and control of the database and the communication channels by using the operating system, system and application software. Furthermore, this relay communicates with the **DSP** and responds to results calculated by the DSP or events read over the digital inputs.

Figure 8 further includes the ***MEMORY*** bank that is used as a temporary storage, code memory and storage for parameters and settings of the relay. Moreover, the bank stores factory calibration settings in the parameter FLASH memory.

The DSP is used for calculations necessary to handle data received over the analogue inputs. These inputs are used to monitor power line voltages and currents.

Figure 8 also shows the ***INTERFACES*** module including the **CAN** unit. In high-end subfamilies, CAN is used for the communication between different modules placed on separate PCBs.

The same INTERFACES module includes a **LON-bus** interface used for remote control communication between relays and for the transfer of large amounts of data.

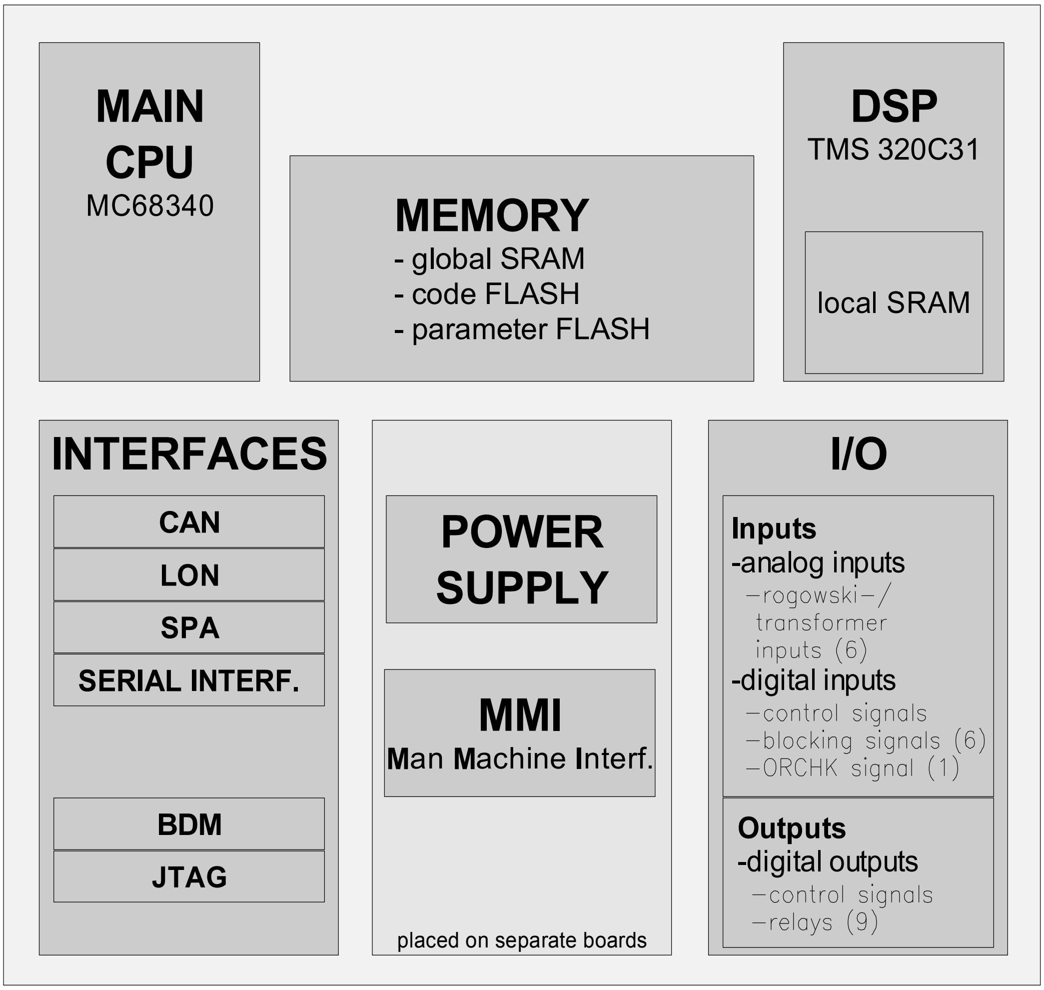

Figure 8. A typical build-up of a higher-level relay of the RED 500 family [1].

Furthermore, "goodies-cards"* are also using the CAN bus to measure sound, vibration and temperature, etc. and to measure partial discharges. These cards use the CAN for e.g. data exchange purposes.

*) cards designed for special services and functions

The **SERIAL INTERFACE** can be used for connecting the relay to computer systems like PCs e.g. to configure the relay or to control the relay in a more conventional way, as is done when a built-in MMI or MIMIC is used. The use of a PC allows the user to display and enter data in a more “easy-to-configure” way.

Software like pROBE+ (running on the relay) and XRAY (running on the PC) use the serial interface for data exchange. These two software tools offer powerful debugging functions during the development phase.

The **BDM** is used to download programs to the relay and to test/debug the software. **JTAG** enables the hardware of the relay to be tested. This is mainly of interest during the production process.

Figure 8 also presents the ***POWER SUPPLY*** module. This unit is located on a separate PCB and supplies the power needed by the whole relay.

Further, you find the ***MMI*** module in the picture**.** The local MMI consists of a two-row LCD, three status LEDs and six buttons to control the relay’s functions. The MMI shows the user the actual status of the relay. The MMI is a separate PCB in the relay. All the other cards are connected together through a backplane board (card) and so they are in electrical contact and communicate with each other. The MMI board is placed behind the front panel.

In some versions you can find a graphic solution instead of the MMI. This is the ***MIMIC*** that also operates as a control interface for the user. It includes the same elements as the MMI, but it also allows a graphic setup and view of the network configuration.

The ***I/O*** module which is the same as the IN/OUT module shown in Figure 8 includes three different types of I/Os.

First, the ***Analog inputs*** that offer 6 analog input channels used to measure voltages or currents on the power lines. Here transformers or Rogowski coil inputs operate as the interface between the relay hardware and the electrical network monitored. The DSP takes care of the computing of the analog values and the control of the programmable input amplifier and the analog digital converter.

Secondly, the ***Digital inputs*** that are used by the CPU to obtain information about internal units/devices (including status information, control signals, setup information and test signals that are externally connected to the relay, e.g. blocking inputs), and data from the keyboard.

Thirdly, the ***Digital outputs*** that are implemented in the system to fulfil the need for control output information from internal units (e.g., LON, DSP, interfaces and MMI) and external units or conventional output relays connected through the interfaces (contacts) of the relay.

2.5.2.1 HW MODULES OF RED 500 RELAYS

The actual communication between the modules can be implemented in different ways. Figure 9 shows a *multicard* and *multiprocessor* solution. The communication with the sub modules is carried out through the CAN bus.

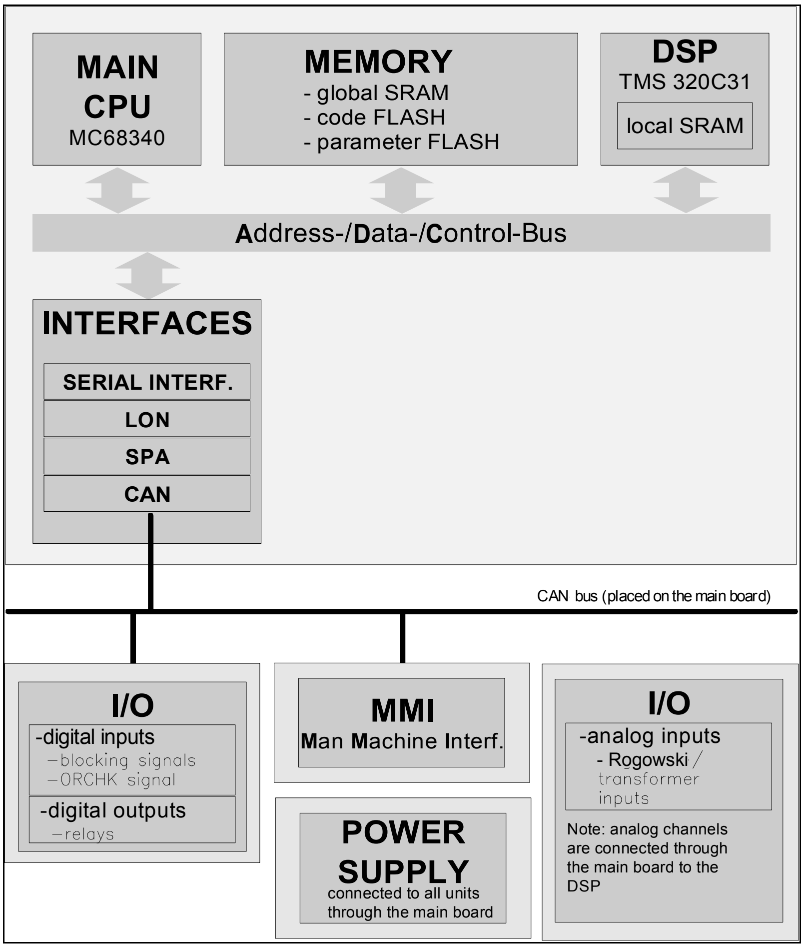

Figure 9. High-end, multicard and multiprocessor relay of the RED 500 family [1].

Figure 9 illustrates a RED 500 relay solution with 5 boards. The CAN bus transfers information between the I/O (digital input/output section) and the MCPU (Main CPU) card. The CAN interface is still available and can be used for the communication with modules from other relay families e.g. REF [1].

2.5.3 TYPICAL FUNCTIONS IN A RED 500 RELAY

There is a number of functions that are usually implemented as described in chapter 2.5.1.3. A typical functional RED 500 relay could include the following functions [1]:

- 3-phase overcurrent function
- Directional earth-fault function
- Motor protection function
- Feeder protection function
- Capacitor bank function
- 3-phase overcurrent and directional earth-fault function
- 3-phase overcurrent and non-directional earth-fault function
- Restricted earth-fault function
- Directional earth-fault function
- Zero sequence voltage function
- 3-phase voltage function
- Synchrocheck function

Above mentioned functions are explained in the chapter OTHER EXPRESSIONS AND THEIR MEANING in the end of this thesis.

2.6 MOTIVATIONS FOR DESIGNING A NEW RELAY SYSTEM

To understand the need for the MBS 1000 system we have to return to the beginning of the era of the microprocessor-controlled relays of ABB.

Formerly, the relay was configured *once* and it was treating data in a certain way, taking care of important decisions. A master monitor (e.g. SRIO 500,1000 or 2000), which sometimes was an "interface" to the human operator in the measuring and monitoring station, made statistics of data received.

Relays have been developed during a long time. However, something revolutionary took place in the 80s: *The SPA bus and the microprocessors were introduced in the relay technology.*

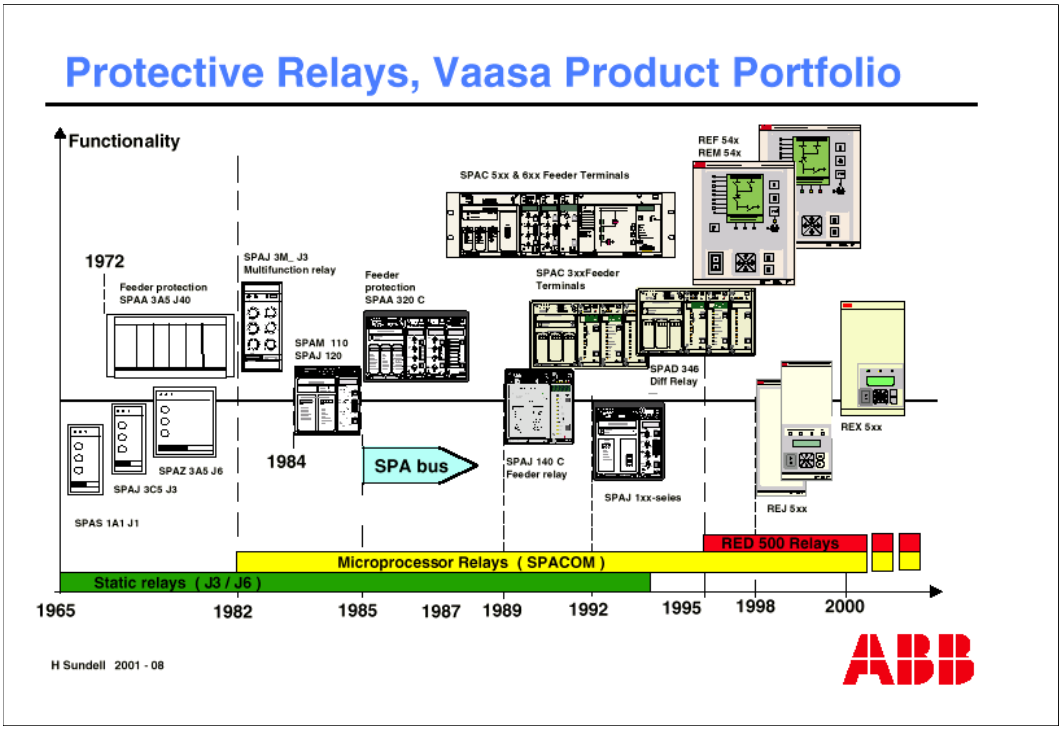

Figure 10. The development from static relays to RED 500 relays in terms of functionality during a period of 35 years **.

Figure 10 shows the relay era from 1965 to 2001. During these years ABB developed many kinds of relays. The figure above illustrates the development from static devices (e.g. SPAS 1A1 J1) to multi-functional, communicating and loadable software relays with a high functional level (REF 54x).

**) I am grateful to Henrik Sundell for letting me use this picture.

The SPA bus introduced in relays in 1985 enabled communication between relay units. In 1997, the RED 500 relays were launched. The purpose of these relays was to make members of the same family software compatible with other. However, there was no similar loadability demand considering the hardware and no good answers to how to solve this problem. The intention was to design a “unit” that was like a PC, with complete software and hardware compatibility and loadable virtual software and hardware, an economical relay, a small relay with few circuits, i.e. a device with FPGA or ASIC solution(s).

2.6.1 PROBLEMS SOLVED BY THIS NEW SOLUTION

The loadability of the SW into a relay system eliminates problems arising when relay software has to be updated, that is, the “forced” personal contact with the relay (to install new ROMs). It also eliminates problems arising when the hardware is to be changed, rebuilt or complemented. The aim is a new rebuilding phase strategy. Through code description of the relay and/or relay system, the hardware must be able to act differently at different times and in different situations.

A virtual feature supporting both hardware and software description on both hardware and software level of the relay system had to be added. This design eliminates the problems with not-all-software/hardware-fits-in-situations of relay and/or relay system ROMs or FLASHs. By downloading new elements from a virtual memory bank the relay(s) and/or relay system(s) immediately undertakes new software and hardware tasks/functions.

There will, however, be some limitations if the conventional hardware does not include the required number of measuring hardware channels.

2.6.2 FORMER SOLUTIONS TO THE SAME PROBLEM(S)

There will be a long development process before all the present needs can be fulfilled by new and/or other construction strategies in the production of a relay. The former method would not have made the product profitable when the market’s demands on the product increased and the costs connected to the development of software and hardware increased.

The old way of updating software was to build a new software application in the design department, test it and then install the new code, which resulted in “forced” up-dates of many ROMs around the world. The update had to be installed in the relay and new user manuals were required. This was a very time-consuming process. Another question was whether there were enough designers available in the design department. The SW loadability eliminated some of these problems in the RED 500 relay system, however not all.

For the hardware, the old way of updating was to build a new prototype of the relay hardware and then test it. The launch of a new product required new manuals, engineering and production phases.

These demands resulted in a very long design time for new products. Some of this time was compensated later when ABB introduced module-based systems. The modules, however, had to be reconstructed when new demands came up.

The old way to solve problems with limited relay data and code memory was to extend the memory. As a result, the size and the price of the hardware increased.

To find new solutions and eliminate the previous problems we had to start by specifying a new system. It was also necessary to speed up the processes executed in master or slave units.

3 RELAY COMPARISON AND ANALYSIS

To analyse the needs for new functions and applications in the MBS 1000 system and make the new system more competitive, it is important to study the functionality of competitors' relay. There are lots of competitors on the relay and relay system market. This comparison and analysis include the five relay manufactures below:

- ABB
- MiCOM
- SIEMENS
- SEL
- MULTILIN

These are the most important relay and relay system manufactures on the market today ***.

In the relay **function** comparison, I compare manufacturers and their respective relays. Some information of the manufacturers is found in OTHER EXPRESSIONS AND THEIR MEANING in the end of this thesis.

3.1 RELAY FUNCTION COMPARISON AND ANALYSIS

To describe the relays of the five manufacturers I have compared some of them as to their functions. This comparison focuses on the number and variety of functions available in the relays.

To be able to find "equal levels" for the competitors, I have only compared the most important and common functions.

The function groups compared are:

- PROTECTION
- CONTROL
- MEASUREMENTS
- POST-FAULT ANALYSIS

***) I am grateful to Henrik Sundell for giving me information about competitive relay manufacturers

- MONITORING
- COMMUNICATIONS
- USER INTERFACE
- SOFTWARE SUPPORT

The terms in this list are explained in chapter 2.2. To find out the meaning of functions in the tables in this chapter, see “OTHER EXPRESSIONS AND THEIR MEANING” in the end of this thesis.

To compare relays with different functions is a challenge, because you can compare relays’ functionality in many ways depending on the concerned relays’ “specialities”. Therefore the number of functions and corresponding functions of the competitor’s relays, including the usability of the functions will be the focus of this comparison.

The function analysis includes elements like grouping similar types of functions into subcategories. The next phase is to define the availability of a specific function and assess the separate functions by giving them points. The points are defined for every subcategory. To be able to compare members of a subcategory, the points are based on the **number** (n number of functions gives n points) and the **existence** (the existence of a function gives 1 point and no existence of the function gives 0 point) of the functions of the subcategory and on common attributes available in all members of that subcategory. In some subcategories, the total points are higher than in others because here points are not based only on the existence or the number of the functions but also on the **capacity** of these functions (e.g. “disturbance max record” or “number of characters” in the LCD). In the subcategory programmable scheme logic, I only compare the total number of points of the services (number of logic inputs, outputs and setting groups), which also results in a higher number of points.

The points of each function and subcategory are added and then a list of points for each function and subcategory of the concerned relay family is received. The priority of each function and subcategory (given in brackets) is defined and based on the usability of and the need for the concerned functions of the relay. The points referring to priority are received by multiplying the priority number with the points of the separate functions. The aim of the table study phase is to find the winner(s) of the separate functions and subcategories and the “overall” winner. If there is a specific reason for a certain result, comments are given.

3.1.1 COMPARISON AND ANALYSIS OF PROTECTION FUNCTIONS

The *protection* functions are the most important functions of the relay. In many cases a relay may be classified according to the protection functions [my comment]. These functions give the **user** an idea of the complexity of the relay. The data used in this chapter is based on the list of protection functions supported by the different manufacturers. The list is found in Appendix 1 in the end of this thesis.

Table 1 contains the number of points received by the different relay types. Points indicating priority are given in brackets.

PROTECTION functions subcategories (priority)	ABB REX 521 (points including priority)	ABB REF 541 (points including priority)	ABB DPU2000 (points including priority)	MiCOM P140 (points including priority)	SIEMENS 7SJ512 (points including priority)	SEL-251 (points including priority)	SEL-351 (points including priority)	MULTILIN SR750 (points including priority)
Points (9) Current functions	2 (18)	2 (18)	3 (27)	**5** (**45**)	2 (18)	2 (18)	4 (36)	3 (27)
Points (8) Earth fault functions	2 (16)	2 (16)	2 (16)	**5** (**40**)	4 (32)	1 (8)	2 (16)	2 (16)
Points (1) Wattmetric characteristic functions	0 (0)	0 (0)	0 (0)	**1** (**1**)	0 (0)	0 (0)	0 (0)	0 (0)
Points (7) Voltage functions	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Points (5) Thermal functions	**1** (**5**)	**1** (**5**)	0 (0)	0 (0)	**1** (**5**)	0 (0)	0 (0)	0 (0)
Points (6) Frequency functions	**2** (**12**)	0 (0)	**2** (**12**)	0 (0)	0 (0)	0 (0)	**2** (**12**)	**2** (**12**)
Points (4) Broken detector functions	**1** (**4**)	0 (0)	0 (0)	**1** (**4**)	0 (0)	0 (0)	0 (0)	0 (0)
Points (3) Curve functions	1 (3)	1 (3)	**3** (**9**)	2 (6)	1 (3)	1 (3)	2 (6)	**3** (**9**)
Points (2) Cold load Pick-up functions	0 (0)	0 (0)	**2** (**4**)	1 (2)	0 (0)	1 (2)	1 (2)	**2** (**4**)

Table 1. Total points (points including priority) for each subcategory of protection functions of the relays compared.

In the subcategories *current functions* (the points are based on the number of *current* functions available in the relay type), *earth fault* (the points are based on the number of *earth-fault* functions available in the actual relay type) and *wattmetric characteristic fault* functions (the points are based on the number of *wattmetric characteristic fault* functions available in the actual relay type) MiCOM's **P140** relay is the winner. The reason is that this relay includes the highest number of the functions mentioned. In the subcategory *Voltage* functions all the relay types get the same number of points, and there is no winner.

In the subcategory *thermal functions* (the points are based on the number of *thermal protection* functions available in the actual relay type) ABB's **REX 521** and **REF 541** and SIEMENS' **7SJ512** are the winners. The reason is that these relays include the highest number of the functions concerned.

In the subcategory *frequency functions* (the points are based on the number of *frequency* functions available in the actual relay type) ABB's **REX 521, DPU2000** and **SEL-351** and MULTILIN's **SR750** are the winners. The reason is that these relays include the highest number of frequency functions.

In the subcategory *broken detector functions* (the points are based on the number of *broken detector* functions available in the relay type) ABB's **REX 521** and MiCOM's **P140** are the winners. The reason is that these relays include the highest number of the concerned functions.

The winner of the subcategories *curve* (the points are based on the number of *curve* functions available in the relay type) and *cold load pick-up* (the points are based on the number of *cold load pick-up* functions available in the relay type) is ABB's **DPU2000**. The reason is that this relay includes the highest number of the concerned functions.

PROTECTION functions subcategories	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Sum of all functions including priority	58	42	68	**98**	58	31	72	68

Table 2. Total points (including priority) for protection functions in different relays.

Table 2 shows the added points including priority for every subcategory of protection functions of the different relay types. MiCOM's **P140** is the winner with 98 points. The reason for the difference between MiCOM and the other relays is MiCOM's great number of current and voltage functions and the high priority of these functions.

3.1.2 COMPARISON AND ANALYSIS OF CONTROL FUNCTIONS

The control functions incorporated in the relay can be used for setting and configuring the relay, thus allowing the user to use the relay for different applications. Data used in this chapter is based on the list of control functions supported by different manufacturers, see Appendix 2 in the end of this thesis.

Table 3 shows the points received by the different relay types for the subcategory control functions. Total points including priority are shown in brackets.

In the subcategory *Programmable scheme logic* (the given points are based on the availability of the *programmable scheme logic* function (1) in the concerned relay (all types)), all the relays compared get the same number of points, except SIEMENS' **7SJ512**, which does not include this function at all.

CONTROL functions subcategories (priority)	ABB REX 521 (points including priority)	ABB REF 541 (points including priority)	ABB DPU2000 (points including priority)	MiCOM P140 (points including priority)	SIEMENS 7SJ512 (points including priority)	SEL-251 (points including priority)	SEL-351 (points including priority)	MULTILIN SR750 (points including priority)
Points (1) Programmable scheme logic	1 (1)	1 (1)	1 (1)	1 (1)	**0 (0)**	1 (1)	1 (1)	1 (1)
Points (3) Auto-reclose Check Synch and CB control	**3** (**9**)	2 (6)	2 (6)	**3** (**9**)	2 (6)	2 (6)	**3** (**9**)	**3** (**9**)
Points (2) Load shedding and restoration	0 (0)	0 (0)	**1** (**2**)	0 (0)	0 (0)	0 (0)	**1** (**2**)	**1** (**2**)
Points (4) Programmable logic inputs, outputs and setting groups	17 (68)	**29/45/62** (**116/ 180/ 248)**	22 (88)	19/34 (76/ 136)	8 (32)	16 (64)	25 (100)	23 (92)

Table 3. Total points (points including priority) of every subcategory of the relays' control functions.

In the subcategories *Auto-reclose, Check Synch* and *CB control* (all points are based on the existence of the concerned function in the relay), there are four winners: ABB's **REX 521**, MiCOM's **P140**, **SEL-351** and MULTILIN's **SR750**. Some of these relays include some of these functions, whereas others do not include any function at all.

In the subcategory *Load shedding and restoration* (the points are based on the availability of the function), ABB's **DPU2000, SEL-351** and MULTILIN's **SR750** get the highest number of points as they include the concerned functions. In the subcategory *Programmable logic inputs*, *outputs* and *setting groups* (the points are based on the number of logic inputs, outputs and predefined setting groups), ABB's **REF 541** wins. Even though the REF 541 relay includes just a few setting groups, it wins due to the great amount of logic inputs and outputs.

CONTROL functions subcategories	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Sum of all functions added (minimum "combination") including priority	78	**123**	96	86	38	71	112	104
Sum – all functions added (maximum "comination") including priority	78	**255**	96	146	38	71	112	104

Table 4. Total points (including priority) for the control functions of the different relays.

Table 4 presents two sums of points including priority - a minimum sum and a maximum sum. These sums are hardware-dependent considering the control subcategories compared to of each type of relay respectively. Here ABB's REF 541 is a clear winner with 123 and 255 points.

The reason for this difference in points is that ABB´s REF 541 relay offers a great number of programmable inputs, outputs and setting groups, plus the fact that these functions are of a high priority.

3.1.3 COMPARISON AND ANALYSIS OF MEASUREMENT FUNCTIONS

To be able to "understand" the components of a power line we have to measure these components in a system. The measurement functions of a relay takes care of measurements and filtering of the inputs connected to the relay. The data used in this chapter is based on the list of measurement functions (see Appendix 2) supported by different manufacturers.

Table 5 shows the number of points received by the different relays. Points including priority are given in brackets.

In the subcategory *Current functions* (the points are based on the number of the different *current* functions available in the relay type), ABB's **REX 521** and **REF 541**, MiCOM's **P140** and **SEL-351** are the winners. The reason is that these relays include the largest number of current functions.

In the subcategory *Voltage functions* (the points are based on the number of different *voltage* functions available in the relay type), ABB's **REX 521** and **REF 541**, MiCOM's **P140**, **SEL-351** and MULTILIN's SR750 are the winners. The reason is that these relays include the largest number of voltage functions.

MEASUREMENT functions subcategories (priority)	ABB REX 521 (points including priority)	ABB REF 541 (points including priority)	ABB DPU2000 (points including priority)	MiCOM P140 (points including priority)	SIEMENS 7SJ512 (points including priority)	SEL-251 (points including priority)	SEL-351 (points including priority)	MULTILIN SR750 (points including priority)
Points (6) Current functions	**2** (**12**)	**2** (**12**)	1 (6)	**2** (**12**)	1 (6)	1 (6)	**2** (**12**)	1 (6)
Points (5) Voltages functions	**2** (**10**)	**2** (**10**)	1 (5)	**2** (**10**)	1 (5)	1 (5)	**2** (**10**)	**2** (**10**)
Points (1) Power functions	**5** (**5**)	4 (4)	3 (3)	4 (4)	3 (3)	0 (0)	3 (3)	4 (4)
Points (4) Frequency functions	1 (4)	1 (4)	1 (4)	1 (4)	**0** (**0**)	1 (4)	1 (4)	1 (4)
Points (3) Demand functions	2 (6)	2 (6)	2 (6)	2 (6)	**0** (**0**)	2 (2)	2 (2)	2 (2)
Points (2) Energy functions	1 (2)	1 (2)	1 (2)	1 (2)	**0** (**0**)	**0** (**0**)	1 (2)	1 (2)

Table 5. Total points (points including priority) of measurement functions in the relay families compared.

In the subcategory *Power functions* (the points are based on the number of *power* functions available in the relay type), ABB's **REX 521** is the winner. The reason is that this relay includes the largest number of power functions.

In the subcategories *Frequency* and *Demand functions* (the points are based on the number of *frequency* and *demand* functions available in the relay type), SIEMENS's 7SJ512 is the loser. The reason is that this relay does not include any of these functions and so the number of points for the function is zero.

In the subcategory *Energy Functions* (the points are based on the number of *Energy functions* available in the relay type), SIEMENS's 7SJ512 and SEL-251 are the losers. The reason is that these relays do not include any energy function at all and so the number of points is zero.

MEASUREMENT functions subcategories	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Sum of all functions including priority	**39**	38	26	38	14	17	33	28

Table 6. Total points (including priority) of measurement functions of the different relays.

Table 6 shows the total points including priority of all measurement function subcategories of the individual relay types. Here ABB's **REX 521** is the winner with 39 points.

Here we do not find any major differences between the relays. However, the advantage of ABB's relay REX 521 in the number of power functions offered gives this relay one point more than the others, though the function is of low function priority.

3.1.4 COMPARISON AND ANALYSIS OF POST-FAULT FUNCTIONS

To be able to follow up events on the network we have integrated post-fault functions into the relay. These functions record faults and events related to the network, allowing the user to trace and analyse them afterwards.

The data used in this chapter is based on the list of post-fault functions offered by different manufacturers, see Appendix 3 in the end of the thesis.

Table 7 shows the post-fault functions included in the relays and the number of points received by the separate relays (points including priority are given in brackets).

In the subcategory *IRIG-B function control* (the points are based on the availability of the *IRIG-B function* in the relay), MiCOM's **P140, SEL-251**, **SEL-351** and MULTILIN's **SR750** are the winners. The reason is that these relays include the concerned function.

In the subcategory *Fault* and *Event recording functions* (the points are based on the length of the *Fault* and *Event record function* buffers in the relay type), MiCOM's **P140** is the winner, because this relay includes the largest buffers.

In the subcategory *Disturbance recording function* (the points are based on the length of the *Disturbance record function* buffers in the concerned relay type), ABB's **REX 521** is the winner.

POST-FAULT ANALYSIS functions subcategories (priority)	ABB REX 521 (points including priority)	ABB REF 541 (points including priority)	ABB DPU2000 (points including priority)	MiCOM P140 (points including priority)	SIEMENS 7SJ512 (points including priority)	SEL-251 (points including priority)	SEL-351 (points including priority)	MULTILIN SR750 (points including priority)
Points (1) IRIG-B	0 (0)	0 (0)	0 (0)	**1** (**1**)	0 (0)	**1** (**1**)	**1** (**1**)	**1** (**1**)
Points (4) Fault and Event records	51 (204)	2 (8)	160 (640)	**205** (**820**)	4 (16)	13 (52)	2 (8)	101 (404)
Points (3) Disturbance records (max records)	**1066** (**3198**)	0 (0)	1 (3)	20 (60)	20 (60)	12 (36)	15 (45)	1 (3)
Points (2) Fault locator	1 (2)	1 (2)	1 (2)	1 (2)	**0** (**0**)	1 (2)	1 (2)	1 (2)

Table 7. Points (points including priority) of post-fault analysis functions of the different types of relays.

The reason is that this relay includes the largest recording buffer. In the subcategory *Fault locator* the points are based on the availability of the *Fault locator function* in the concerned relay. Being the only relay without this function SIEMENS's 7SJ512 is the loser.

POST-FAULT ANALYSIS functions subcategories including priority	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Sum of all functions (including records)	**3404**	10	645	883	76	91	56	410

Table 8. Total points (including priority) of post-fault analysis functions in the relays tested.

Table 8 shows the total amount of points, including priority, of all subcategories of post-fault functions for each relay type. ABB's **REX 521** is the winner with 3404 points (with the maximum configuration).

The reason why ABB's relay REX 521 is superior to the others is its length of disturbance recording buffer(s) (even though the priority of function is low).

3.1.5 COMPARISON AND ANALYSIS OF MONITORING FUNCTIONS

To keep system reliability under control, the system incorporates monitoring and self-supervision functions. The monitoring functions of the relays include self-supervision of the relay itself and the system connected to the relay.

MONITORING functions subcategories (priority)	ABB REX 521 (points including priority)	ABB REF 541 (points including priority)	ABB DPU2000 (points including priority)	MiCOM P140 (points including priority)	SIEMENS 7SJ512 (points including priority)	SEL-251 (points including priority)	SEL-351 (points including priority)	MULTILIN SR750 (points including priority)
Points (4) Monitoring functions	**3** (**12**)	2 (8)	2 (8)	**3** (**12**)	1 (4)	**3** (**12**)	**3** (**12**)	2 (8)
Points (3) Supervision functions	**3** (**9**)	2 (6)	1 (3)	**3** (**9**)	1 (3)	0 (0)	1 (3)	1 (3)
Points (1) Sensor inputs functions	**1** (**1**)	**1** (**1**)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Points (2) CB failure functions	1 (2)	**0** (**0**)	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)

Table 9. Relay type and points received (points including priority) for monitoring functions.

The data used in this chapter is based on a list of monitoring functions supported by different manufacturers, see Appendix 3 in the end of this thesis.

Table 9 shows the number of points received by the different relay types in terms of monitoring functions. Total points including priority are given in brackets.

In the subcategory *Monitoring functions* (the points are based on the availability of *monitoring functions* in the respective relay), ABB's **REX 521**, MiCOM's **P140, SEL-251** and **SEL-351** are the winners. The reason is that these relays include monitoring functions.

In the subcategory *Supervision functions* (the points are based on the availability of *supervision functions* in the respective relay), ABB's **REX 521** and MiCOM's **P140** are the winners**.** The reason is that these relays include supervision functions.

In the subcategory *Sensor input functions* (the points are based on the availability of *sensor input functions* in the respective relay), ABB's **REX 521** and **REF 541** are the winners. The reason is that these relays include sensor input functions.

In the subcategory *CB failure functions* (the points are based on the existence of *CB failure functions* in the respective relay), ABB's **REF 541** is the loser because it is the only relay that does not include CB failure functions.

MONITORING functions subcategories including priority	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Sum of all functions	**24**	15	13	23	9	14	17	13

Table 10. Total points (including priority) of monitoring functions for the different relay types.

Table 10 shows the total points, including priority, for all monitoring functions of each relay type. As we can see, ABB's **REX 521** is the winner with 24 points. The reason for the superiority of ABB's REX 521 relay by one point is the missing sensor input functions of MiCOM P140.

3.1.6 COMPARISON AND ANALYSIS OF COMMUNICATION FUNCTIONS

The number of communication ports and protocols are strongly related to the communication capability of the relay. The communication functions of the relays take care of the relay's communication configuration.

The data used in this chapter is based on the list of monitoring functions supported by the different manufacturers (see Appendix 4 in the end of this thesis).

Table 11 shows the points received by the different relays types in the comparison of the communication functions. Total points including priority are shown in brackets.

In the subcategory *Port functions* (the points are based on the number and types of ports available in the relay type), ABB's **REF 541** and **DPU2000**, SIEMENS' **7SJ512** and MULTILIN's **SR750** are the winners. The reason is that these relays include the largest number of ports and port types.

In the subcategory *Protocol functions* (the points are based on the number of *Protocol functions* existing in the concerned relay type), ABB's relays **REX 521**, **REF 541, DPU2000** and MiCOM's **P140** are the winners. The reason is that these relays have more protocol functions than the others.

COMMUNICATION functions subcategories (priority)	ABB REX 521 (points including priority)	ABB REF 541 (points including priority)	ABB DPU2000 (points including priority)	MiCOM P140 (points including priority)	SIEMENS 7SJ512 (points including priority)	SEL-251 (points including priority)	SEL-351 (points including priority)	MULTILIN SR750 (points including priority)
Points (4) Ports	2 (8) RS 232, Fibre optic	**3** (**12**) RS 232, RS 485, Fibre optic	**3** (**12**) RS 232, RS 485, Fibre optic	2 (8) RS232, RS485	**3** (**12**) V.24, RS 485, Fibre optic	1 (4) RS232	1 (4) RS232	**3** (**12**) RS485, RS422, RS232
Points (3) Protocol	**3** (**9**) LON Bus SPA Bus IEC - 103	**3** (**9**) LON Bus SPA Bus VDEW6	**3** (**9**) SPA Bus MODBUS INCOM	**3** (**9**) Courier, Modbus, IEC -103	1 (3) VDEW	1 (3) ASCII	2 (6) DNP3.0 ASCII	1 (3) Modbus
Points (1) No. of poss. relays in daisy chain	0 (0)	0 (0)	**32** (**32**) 32 for RS485	**32** (**32**)	1 (1)	1 (1)	1 (1)	**32** (**32**)
Points (2) Diagnostic functions	**0** (0)	**0** (0)	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)

Table 11. Relay type and subcategory with points (points including priority) when communication functions are compared.

In the subcategory *Num. (ber) of poss. (ible) relays in daisy chain* (the points are based on the *number of possible relays in daisy chain* of the concerned relay type), ABB's relay **DPU2000** and **MiCOM's P140** are the winners. The reason is that these relays include the largest number of possible relays in the daisy chain.

In the last subcategory called *Diagnostic functions* (the points are based on the availability of *Diagnostic functions* in the respective relay), ABB's relays **REX 521** and **REF 541** are the losers. The reason is that these relays do not include diagnostic functions at all.

Table 12 shows the total points, including priority, of all subcategories of the communication functions of the relay types compared. We find that ABB's relay **DPU2000** offers the highest communication functionality and is the winner with 55 points.

COMMUNICATION functions subcategories	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Sum of all functions including priority	17	21	**55**	51	18	10	13	49

Table 12. Sum of all points (including priority) of communication functions of the relays compared.

Here ABB's DPU2000 is superior to MiCOM's P140 and MULTILIN's SR750. ABB's, MICOM's and MULTILIN's relays are superior to the other relays in offering 32 relays in the daisy chain, though this function is of low priority.

3.1.7 COMPARISON AND ANALYSIS OF USER INTERFACE FUNCTIONS

To be able to communicate with a relay, for instance, to set and configure the relay, the user needs a MMI. The user interface takes care of all the functions needed for the communication between the user and the relay. The data used in this chapter is based on the list of user interface functions presented in Appendix 4.

Table 13 shows the points the different relay types get for their user interface functions. Total points including priority are shown in brackets.

In the subcategory *N character display function* (the points are based on the *number of possible characters displayed* in the actual relay type), ABB's **REF 541** is a strong winner as it displays both capital letters and small characters, and graphic.

USER INTERFACE functions subcategories (priority)	ABB REX 521 (points including priority)	ABB REF 541 (points including priority)	ABB DPU2000 (points including priority)	MiCOM P140 (points including priority)	SIEMENS 7SJ512 (points including priority)	SEL-251 (points including priority)	SEL-351 (points including priority)	MULTILIN SR750 (points including priority)
Points (3) n character display	32 (66)	**490** (**1470**) Large LCD (in char. Mode > 70x7 ch.)	80 (240)	32 (66)	32 (66)	0 (0)	20 (60)	40 (120)
Points (2) LEDs (max setup)	3 (6)	13 (26)	13 (26)	5 (10)	8 (16)	8 (16)	16 (32)	**20** (**40**)
Points (1) No. of default messages	0 (0) (when un-known)	0 (0) (when unknown)	1 (1)	12 (12)	0 (0) (when unknown)	0 (0)	16 (16)	**20** (**20**)

Table 13. Points of relay types and subcategories (including priority) of User Interface functions.

In the subcategory *LEDs* (the points are based on the number of LEDs available in the concerned relay type), MULTILIN's **SR750** is the winner. The reason is that this relay is provided with the highest number of status indicating LEDs.

In the subcategory *Number of default messages* (the points are based on the *Number of default messages* offered by the relay type), MULTILIN's **SR750** is the winner. The reason is that this relay includes the highest amount of default messages.

Table 14 presents the total amount of points, including priority, of the subcategories of the user interface functions of the relay types compared. We find that ABB's relay **REF 541** gets the highest amount of points, i.e. 503, in user interface functionality and so is the winner.

USER INTERFACE functions subcategories	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Sum of all functions	35	**503**	94	49	40	8	52	80

Table 14. Total points (including priority) of user interface functions offered by the relays compared.

The reason for the difference between ABB's REF 541 and the other relays is the big LCD of REF 541 and the high priority of user graphic interface functionality and services.

3.1.8 COMPARISON AND ANALYSIS OF SOFTWARE SUPPORT FUNCTION

To be able to set up, configure and use the system from a PC, we need software tools. Software support includes tools used in a separate unit, allowing the user to e.g. set up a relay unit.

The data used in this chapter is based on the list of the user interface functions presented in Appendix 4 of this thesis.

SOFTWARE SUPPORT functions category	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
Points SOFTWARE SUPPORT	**3**	**3**	1	2	2	1	1	1

Table 15. Relay types and category including software support functions.

Table 15 shows the number of software support tools (upon which the points are based) for the relay types compared.

There is no priority scale in this table because there is only one function category. The table shows that the winners of the software support functionality are ABB's relays **REX 521** and **REF 541**. The reason is that these relays include the highest number of software tools.

There is no major difference between the relays, because this comparison only includes a small number of software modules offering support for the user.

3.2 SUMMARY OF RELAY FUNCTION COMPARISON AND ANALYSIS

The comparison of the relay functions ends with a general table presenting the added points of the separate subcategories. This is followed by the analysis phase where advantages and disadvantages of the subcategories are studied and the winner of the relays compared is appointed.

The data used in this chapter is based on the tables containing the total number of points of the subcategories presented in chapter 3.1.

Table 16 shows the added points, including priority, of the different subcategories. The winners of the subcategories are in bold. The points are defined as explained in the chapter describing the concerned subcategory.

Functions subcategories	**Type of Relays** (total points of separate subcategories)							
	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
PROTECTION	58	42	68	**98**	58	31	72	68
CONTROL Minimum/maximum setup state	78	**123/255**	96	86	38	71	112	104
MEASUREMENTS	**39**	38	26	38	14	17	33	28
POST-FAULT ANALYSIS	**3404**	10	645	883	76	91	56	410
MONITORING	**24**	15	13	23	9	14	17	13
COMMUNICATION	17	21	**55**	51	18	10	13	49
USER INTERFACE	35	**503**	94	49	40	8	52	80
SOFTWARE SUPPORT	**3**	**3**	1	2	2	1	1	1

Table 16. Sum of points of the separate subcategories, including priority points. The winner is in bold.

Table 17 shows the total points of all subcategories for the relays compared in this examination (table 16).

Functions subcategories	**Type of Relays** (total points of all subcategories)							
	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
SUM OF ALL SUBCATEGORIES	**3658**	755/887	998	1230	255	243	356	753

Table 17. Total points of all subcategories, including priorities, for the relays compared.

With a total of 3658 points, ABB's relay **REX 521** is the winner of the relays. The great difference between the winner and the second relay, MiCOM P140, mainly depends on the subcategory *Post-fault Analyses*. The disturbance recording buffer of the winning relay is large and the post-fault analysis function is of high priority.

Figure 11 contains a graphic presentation of the added points (including priority) for each subcategory included in the comparison of the relays.

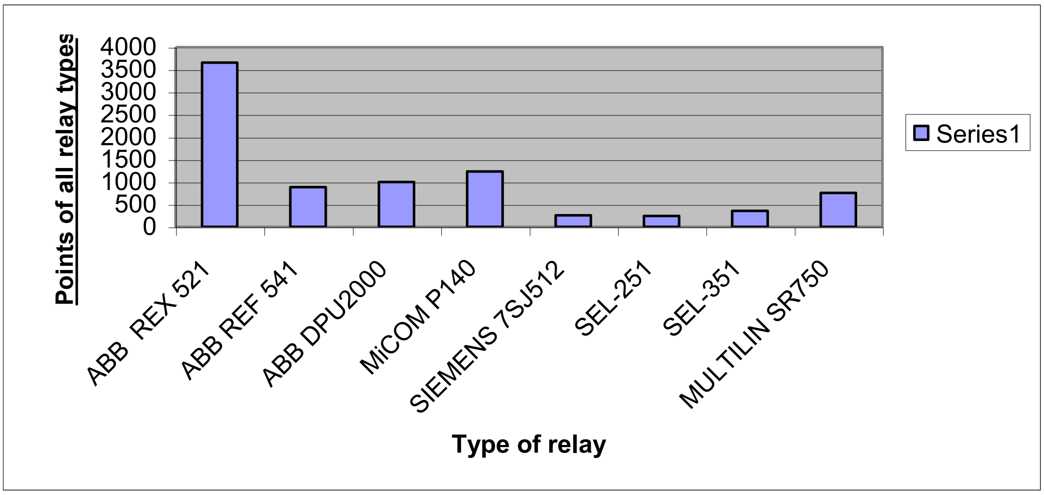

Figure 11. Graphic presentation of total points including priority of the relays compared.

The *second* relay after the *winning* relay **REX 521** is **MiCOM's P140** relay. ABB's relays **DPU 2000** and **REF 541** are in the *third* and *fourth* place respectively, MULTILIN's **SR750** in the *fifth* place, **SEL-351** in the *sixth* place, Siemens **7SJ512** in the *seventh* place and finally the relay type **SEL-251** in the *last* place.

As shown in the figure, the differences between the relay **7SJ512** in the seventh place and the relay **SEL-251** in the last place are small. The main reason for the last position of SEL-251 is a combination of the post-fault analysis, communication and user interface functions.

It is not easy to compare relays because a comparison can be made based on different aspects, for instance, from the viewpoint of the user, the economy, functionality, speed, etc.

The same function may get different points depending on who is using the relay. For one user a certain function is significant and for another user that does not need that specific function another function is more important.

Depending on the technological development, some functions that today gets few points might tomorrow get much more points. In some countries a certain function may be a must, whereas in another country the function is not necessary.

The comparison of relays including other attributes, leads us to the conclusion that the next generation of relays, i.e. the new MBS 1000, should have a dynamic character as regards both hardware and software. It must be possible to load new features and “roles” into the relay, both on the hardware and the software level.

New properties and “capacities” should be implement able in minutes in the same hardware. This would satisfy many users’ expectations and needs. In this way, we can compensate for many of the drop-off features that old relays incorporated that and competitors have included in their relays.

4 THE NEW MBS 1000 RELAY SYSTEM IN GENERAL

The new MBS 1000 system introduces a new way of thinking with faster responses from slaves and a higher quality of products, units and modules from ABB worldwide. A new way of thinking has been introduced by the new way of looking at old relay products and the new technology on the market today.

Initiatives have been taken to find solutions to the new technology and meet the challenges posed by the new generation and second-level revolution. The second level considers both hardware and software of this new MBS 1000 protection relay system. The new MBS 1000 system offers high-quality products with fast feedback from customers all around the world. This new system offers full data access of any unit.

The aim of the system is to beat all competing systems seen or hidden on the power distribution network protection market - no matter of price, flexibility or complexity of the systems.

The term MBS 1000 *virtual relay* stands for a wide dynamic functionality with flexible hardware and software. A new function or configuration can be loaded into a relay even under the normal operation of the relay. Functions can be located practically anywhere and anyhow in the target relay. The functions are found in the function centre and the library of the MBS 1000. Once a function has been initialised, the unit starts using it. Should the needed software or hardware not be found, the current configuration system loads the missing parts of the hardware and/or software into the unit. The same procedure is applied for software and hardware that has been changed in the function centre or library.

It must also be possible to relocate to the function centre configuration, software and hardware that have been changed in the relay.

4.1 MAJOR DIFFERENCES BETWEEN RED 500 AND MBS 1000

The differences between the RED 500 system and the MBS 1000 system can be described by several attributes. In recent years, we have found that *it is not just the software but also the hardware of RED 500 that must be freely configurable.*

Other things to be improved is *the speed of the buses* and *response time decrement.* Further it is necessary to *implement and integrate some software elements into the hardware* and make the *configuration on a visual or verbal level*.

It should be possible to *load data or code not found in the cache memory* (virtual code&data memory) and the *system code and data (both software and hardware)* into the relay.

The MBS 1000 relay family will be capable of more controls, polling and interpretation of commands received from the units over a high speed GIGA-bit bus. This means that the unit performs “basic” computing and interpretation of the data received and forwards a message, if necessary, to let the main unit continue the processing of it. The bus interfaces will operate as independently as possible, without requesting the main CPU to handle these messages.

The system performance with *“free configuration and control with nearly full data access anytime, anywhere and anyhow*” is taken care of by one or several fast remote bus(es). These buses allow you to configure and fully control the system. Our vision is to implement these attributes in all units of the MBS 1000 relay system.

4.2 FUNCTIONAL DYNAMICS

Once a certain function or functionality of a relay has been deleted, the relay can undertake a new function or role in the system. Configure when you need - use data as long as you need it. Reconfigure and use the relay and new data for new tasks. The MBS 1000 relay system is dynamic in regard of time, application, place and functionality.

These are the attributes that form the basis for the MBS 1000 system. To concentrate information and control that a huge system is providing and still maintain a good overall picture of the whole (even *globally* – through the Internet, the nth generation of telecommunication or satellite) system, one or several high-level service units that supervise the whole system are needed. These units include the main database function’s tasks of the system or the whole system.

To be able to compete with other relay systems, the basic system version should be competitive in price. The components of the system such as relays which are sold as separate units, must also have a low price.

In addition, the system offers special low-price product versions. These are special relays with low production and system working-costs, including just the most important functions.

Under these circumstances, constructors must be able to test the relays during and after the assembly phase.

To be able to load new HW/SW/data/code elements to be used and executed in the relays, the main circuits have to be ASIC or FPGA configurable. To ensure information under any circumstances, the processor and system throughput including a high processing effect, a fast real data-throughput and high-speed remote buses must be guaranteed in the system.

To avoid wrong decisions from being made due to incorrect data or access failures, the system is provided with:

- information encryption
- protocol handlers
- mathematic algorithms for data transformation
- data compression
- data decompression
- firewalls
- virus protection
- electric protection.
- self-supervision

This offers the customer safety and reliability. When updating software/hardsoftware parts, the user must be able to use the same hardware.

The system project managers are responsible for these attributes being under constant control. Accordingly backward/forward compatibility is needed.

To act fast during start-up and maintenance breaks, the system has to be based upon an easy system setup and maintenance philosophy. Some parts of the inner kernels of the relays should enable automatic self-setup, including adjustment of self-setup, logics, artificial intelligence, fuzzy logic or/and neural network support. These features we call the relay’s self-configuration functions. During configuration, the relay normally is in the basic configuration mode.

Under special conditions it must be possible to use a remote bus for the process-controlled configuration of the relay.

The relays of the new MBS 1000 family must be compatible with older relay families to be able to communicate with older systems over communication buses and gateways (translators) for more static solutions or special motors (real-time interpreters). Under special circumstances, the results of signalling and information handling inside the relay can be the relay's own responsibility. Older relays are participant of the communication and can take part in the transmission of information.

By keeping the line "operating system independent", programmers and users can use various programming languages when designing the HW/SW/data/code of the system. When there is one common programming standard supported by the relay's language motor, the local relay could be any type of relay as its interpreter generates its own local "language processor", its own logic language or script to be executed in the operating system.

To use more of the user's senses on a visual level – the configuration is locally and globally implemented by means of graphic displays, which have their own setup symbols and diagrams as if supported from cameras during the configuration procedure. When the user is in contact with the setup part of the relays, the system and relays are **visually configurable**. Also voice support is possible, which means that the relay or the system responds to spoken commands. The system is **verbally configurable**.

To be able to keep all systems and relays under control, it must be possible to connect relays or relay systems to international or national control centre(s).

From the control centre(s) the operator can view and fully control a single relay or a freely configurable group(s) of relays. The system offers the user a worldwide system (even one-to-one-point control). The system gives the user configuration assistance by asking, helping and guiding. The MBS 1000 offers the user interactive configuration.

4.3 DIFFERENT KIND OF FAMILIES INSIDE THE MBS 1000 SYSTEM

The MBS 1000 system includes three major families (SERVER, CONTROLLER and MONITOR family) which are divided into groups with different service and complexity levels. In addition, these families can be divided into subfamilies. The subfamilies have not yet been given a name, but the letters “xx” of the type designation are reserved for the names of the subfamilies and will be replaced by a number later.

The first group of the MBS 1000 relay family is **MBS 11xx** which represents the *basic-range level SERVER relay family* that includes combinations of functions with 3 analog inputs and 4 digital outputs.

The second group of the MBS 1000 relay family is **MBS 13xx**. The relays of this group includes a combination of functions with 4 analog inputs and 4-5 digital outputs. This represents the *medium-range level SERVER relay family.*

The third group *SERVER relay family* and the *large-range level* is represented by **MBS 15xx**. These relays include a combination of 5 or more analog inputs and 5 or more digital outputs connected together.

A special solution that allows a large and an *extended large-range level SERVER relay family* and/or a basic *CONTROLLER relay* model to be built is **MBS 17xx** group.

The highest-level subfamily, i.e. the *CONTROLLER relay* family, is the **MBS 19xx**, which represents the *medium and high solution CONTROLLERS* responsible for signalling between the MBS 11xx and 17xx families. The MBS 19xx family has the highest level of relay function complexity and intelligence of the MBS 1000 relay CONTROLLER-families.

The control centre from which relays or group(s) of relays are controlled is usually provided with a set of PCs (representing the MONITOR family) which are in contact with the units and relays to be controlled. These PCs handle information on a higher control level and they have a more abstract location in the network.

The PCs here are used for *monitoring and control purpose(s),* (SW like SYS 500, COM 500, LIB 5x0 (MicroScada system)) [3] in the main control or supervision center. These PCs are controlled by a supervisor for instance at a power plant and they control a large number of relays connected to the network. In some cases, this function can be distributed to other type of units in the hierarchy as well.

4.4 CONCRETISING OF THE MBS 1000 PROJECT

New technology is being developed very fast. The start of a new project poses new challenges. During the initial part of a project a well-defined goal, a system description and a design plan have to be made. Otherwise there is a risk that various “powers” haze the target.

System description and design form the basis for the next phase when system designers start research to find the right solutions for managing the tremendous amount of information relating to the many solutions to be considering for the different parts of the system. The documentation of the basic solution has to be started as soon as possible to be able to “keep in mind” ideas, suggestions and modifications made in the HW and SW during the research phase.

While studying available information and collecting data that may be needed stronger and more stabilized basic solutions that satisfy the needs appear. This is also where we start the allocation phase by allocating advantages and the appropriate solutions developed during the research phase to a total solution.

Once we have incorporated the required FPGAs or ASICs in the system hardware, we are able to define many applications and so (both HW and SW in and on ASICs or FPGAs) create “modules” for the new relay family.

For many years the SW has been executed by and logically located near the kernel’s processor. The new approach is to divide part of the SW into several elements and new “shapes”.

The result of the dynamic character of the MBS 1000 system is that not only the system but also its modules are freely relocate able (transferable) from one memory block of a subfamily into the memory block(s) of another family, with minor changes in the driver mechanism.

The information research phase must however contain signalling mechanisms that eliminate “irrelevant” research, unnecessary costs and “excessive” HW and SW.

By starting to create a prototype during the “unsafe” suggestion phase we avoid wasting time and remaining in a “research-forever loop”. During the prototype creation phase irrelevant suggestions and solutions usually “die” and we keep the motivation high and at the same the time schedule of the project. New interesting solutions may, however, be considered later in the first real prototype version of the actual module or unit.

The closed part of this thesis presents a roadmap based on the steps suggested. This roadmap allows the MBS 1000 project to be monitored. The same steps can be used for building projects on the HW, SW and documentation levels.

Additionally, when a certain system development phase is initiated, we immediately assign the tasks to come to the work teams concerned and persons involved. The project steps mentioned in the closed part of this thesis are applied for all phases.

5 SUMMARY

In this thesis I introduce the new MBS 1000 relay system with two new dimensions, comparing it to the old RED 500 relay system. The *two new dimensions are* ***loadability of the hardware kernels*** and ***core virtual data/code/configuration*** *of the relay(s).*

To explain the background of this new system I describe the old SPACOM and RED 500 systems and the processor capacity problems we faced during the SPACOM era, when new features had to be added to both the hardware and the software. In this work I emphasize that *there must accordingly be enough power for the execution of the software in the relay.*

By comparing different kinds of relays I give the reader a relevant picture of some of the relays competing with the relays of ABB. The winner of e.g. the current functions group (current functions are of vital importance for a relay) is not ABB's relay but MiCOM's relay. The overall winner relay is ABB's **REX 521**.

It should, however, be said that it is difficult to make a fair comparison of the relays.

I also start the *introduction and preparation of the new system* by giving the reader some *general information about the MBS 1000 relay system* and *explaining the differences between the RED 500 and the MBS 1000 systems.* There are many ways to build a system. I refer to the closed part for detailed information about the step-by-step implementation of the project.

The new system and the next generation of relays should be *dynamic both regarding hardware and software*. It must be possible to implement new properties and capacities in minutes.

In addition, dimensions that satisfy the user's needs for various solutions and applications with the same relay hardware are required. In this way we can compensate for many of the advantages offered by old relays and competitors' relays.

When the MBS 1000 system is implemented, we will be able to create new fast functions and solutions that do not require long development processes as before when the hardware and software of a system was planned and implemented. We have time to pay more attention to the customer.

SAMMANFATTNING

Detta är en sammanfattning av ett examensarbete för Filosofie Magister. Det beskriver *förberedelser* för ett nytt virtuellt reläsystem, MBS 1000 (**M**ega **B**ase **S**ystem **1000**).

Inledning och några av systemets nya dimensioner

År 1995 gav Jarmo Saaranen, dåvarande chef för resultatenheten ABB Transmit Oy, EUR ING Mats BJÖRKQVIST i uppgift att planera, beskriva, specificera, ge förslag på möjliga lösningar och förslag till fullföljande av ett nytt reläsystem, inklusive dokumentation för både hårdvaru- och mjukvarunivån.

Reläsystemet MBS 1000 har utvecklats för att ersätta det nuvarande RED 500 reläsystemet vid ABB Oy, Distribution Automation (senare ABB). Nya intressanta dimensioner hos MBS 1000 är bl.a. att reläet har **laddningsbar hårdvara** (senare HW) samt **virtuell data/kod/konfiguration** av reläet.

Laddningsbar hårdvara berör de tidigare reläernas kretsar som omfattade ingångar, utgångar, konventionell logik, analoga kanaler och mjukvara (senare SW) som handhades av processorn och processorkärnan. Dessa element skall integreras i en eller flera FPGA- eller ASIC-kretsar. Användaren uppdaterar reläet genom att ladda ner nya element och erbjuder utvecklaren och användaren ett fullt dynamiskt koncept.

Dimensionen **virtuell data/kod/konfigurationen** av reläet ger ökad systemhastighet genom att använda mindre RAM med en mycket kort åtkomsttid, vilket resulterar i hög systemprestation. När reläet behöver ny mjukvara eller hårdvara laddas de erforderliga elementen in i respektive målkrets, relädel eller data/kod-minne. Målenheten har endast en liten basmjukvara och -hårdvara.

Reläets funktioner och ABB:s tidigare sätt att skapa en ny produkt

Mellan elstationen och elanvändaren finns det skydds- och kontrollenheter som övervakar flödet av energi i det elektriska nätverket. Dessa enheter som kallas *skyddsreläer* mäter spänningar och strömmar i elnätet.

Ett relä innehåller 8 funktiongrupper:

- **kontroll-** eller **styrfunktionsgruppen** (control) som ger användaren möjlighet av att ställa in och konfigurera reläet

- **skyddsfunktionsgruppen** (protection) som analyserar uppmätta spännings- och strömvärden samt tar beslut baserade på dessa värden

- **mätfunktionsgruppen** (measurement) som bestämmer på vilka sätt mätningarna sker

- **felanalysfunktionsgruppen** (post-fault analysis) som registrerar olika situationer som uppstår i nätet utanför och som senare skall kunna följas upp

- **monitor-** eller **övervakningsfunktionsgruppen** (monitoring) som registrerar felhändelser och abnorma incidenter vid självövervakningen av reläet samt det yttre system som är kopplat till reläet

- **kommunikationsfunktionsgruppen** (communication) som handhar kommunikationen och protokollet mellan en eller flera reläer och kontrollrummet

- **användargränssnittsfunktionsgruppen** (user interface) som gör det möjligt för användaren att kommunicera med, ställa in och konfigurera reläet

- **mjukvarustödfunktioner** (software support) som är verktyg kopplade externt till reläet och som under provning och funktion används för diagnostisering, inställning, kontroll och debuggning av reläet

Tidigare fastställdes ett reläs grundfunktion *en* gång och databehandlingen utfördes på *ett* fastställt sätt. Under 80-talet introducerades inom reläteknologin SPACOM-reläerna som hade en *SPA-buss* och en *mikroprocessor*. SPA-bussen möjliggjorde kommunikation mellan reläenheterna.

År 1997 lanserades RED 500-reläerna. Syftet med dessa vara att mjukvaran hos medlemmarna i samma familj skulle vara kompatibel och laddningsbar. Dock fanns inga krav och lösningar på laddningsbar hårdvara.

Med den nya, kommande relägenerationen MBS 1000 strävar man efter att skapa en reläenhet som fungerar som en PC. Enheterna skall vara mjukvaru- och hårdvarukompatibla med laddningsbar virtuell mjukvara och hårdvara. Ytterligare skall reläenheten vara liten till formatet och ekonomisk samt ha endast ett fåtal FPGA- eller ASIC-kretsar.

Genom nedladdning av nya element från en virtuell minnesbank kan relä(erna) och/eller reläsysteme(t/en) genast anpassa sig till nya mjuk- och hårdvaruuppgifter eller -situationer.

Tidigare metoder för att förbättra lönsamheten hos en produkt var att minska utvecklingskostnaderna för mjukvaran och hårdvaran.

Mjukvaran uppdaterades genom att man byggde en ny mjukvaruapplikation samt testade och installerade den i enheten. Detta resulterade i ett "tvingat" byte av många programminnen runt om i världen. Möjligheten att ladda ned mjukvaran eliminerade några av dessa faktorer i RED 500 reläsystemet, dock inte alla.

Hårdvaran uppdaterades genom att man byggde en ny reläprototyp, testade denna och skapade ett rent nytt relä. Lanseringen av en ny produkt fordrade nya manualer, ingenjörsteknik och flera produktionssteg. Detta resulterade i att konstruktionstiden för en ny produkt var lång. Något av denna tid kunde kompenseras när ABB introducerade modulbaserade system. Dock måste modulerna omkonstrueras då nya fordringar kom upp.

När funktionaliteten utökades uppstod problem med reläets begränsade kod- och dataminne med den påföljden att storleken och priset på relähårdvaran steg.

Jämförelse mellan reläer

För att få en relevant bild av konkurrensen reläer och relätillverkare emellan jämförs ett flertal reläer.

Syftet med denna studie är att finna en vinnare för en separat funktion och underkategori, men även en vinnare för alla reläer. Här jämförs och analyseras reläer från **ABB**, **MiCOM**, **SIEMENS**, **SEL** och **MULTILIN**.

Funktionsgrupperna som jämförs är **protection**, **control**, **measurement**, **post-fault analysis**, **monitoring**, **communication**, **users interface** och **software support** (se tidigare del ”Reläets funktioner och ABB:s tidigare sätt att skapa en ny produkt” för funktionernas betydelse).

Funktionsjämförelsen inkluderar element som gruppering av funktionerna till underkategorier, bestämmande av tillgängligheten av en aktuell funktion, poängsättning av varje funktion genom behovsprövning och analys av funktionen ifråga.

Poängen baseras på **antalet** och **existensen** av funktionen i underkategorin på typiska reläfunktioner tillgängliga i alla medlemmar i kategorin. I några underkategorier baseras poängen på funktionernas **kapacitet** och i någon underkategori på antalet logiska in- och utgångar samt inställningsgrupper.

Prioriteten hos varje funktion och underkategori baseras på användarbarheten och -behovet av de aktuella funktionerna i reläet. De slutgiltiga poängantalen fås genom att man hos varje enskild funktion multiplicerar prioritetssiffran med antalet poäng hos varje enskild funktion.

Vi avslutar jämförelsen med att summera poängen för varje funktion och underkategori och göra en analys av varje underkategori. Detsamma görs även på alla underkategorier tillsammans.

Den första jämförelsen och analysen görs på *protection*-funktionerna, vilka är de viktigaste funktionerna i ett relä. Jämförelsen visar att MiCOM:s **P140** relä är vinnare med 98 poäng. Detta beror på att MiCOM:s relä har ett stort antal ström- och spänningsfunktioner och att var och en av dessa har hög funktionsprioritet.

Den andra jämförelsen och analysen görs på *control*-funktionerna i reläerna. Dessa används för inställning och konfigurering av reläet. Jämförelsen visar två poängsiffror som är hårdvaruberoende. Här är ABB:s relä **REF 541** en klar vinnare med 123 respektive 255 poäng. Orsaken till att ABB:s REF 541 vinner är att reläet erbjuder ett stort antal programmerbara ingångar, utgångar och gruppinställningsmöjligheter samt att dessa funktioner har hög prioritet.

Den tredje jämförelsen och analysen görs på *measurement*-funktionerna. Dessa handhar mätning och filtrering av data från ingångarna.

Jämförelsen visar att ABB:s relä **REX 521** vinner med 39 poäng.

Här kan vi inte se någon speciellt stor skillnad mellan reläerna, men ABB:s relä REX 521 vinner genom att det innehåller ett större antal power-funktioner, trots att funktionen har låg prioritet.

Den fjärde jämförelsen och analysen görs på *post-fault analysis* -funktionerna. Dessa registrerar fel och händelser relaterade till elnätet, för en uppföljning i efterhand. Jämförelsen visar att ABB:s relä **REX 521** är vinnare med 3404 poäng (med maximal konfiguration). Orsaken till detta är längden hos störningsskrivarens minnen.

Den femte jämförelsen och analysen görs på *monitoring*-funktionerna. Dessa sköter självövervakningen av reläet och systemen som är kopplade till detta. Jämförelsen visar att ABB:s **REX 521** är vinnare med 24 poäng. Orsaken till att ABB:s REX 521 relä vann med ett poäng är en sensor-ingångsfunktion som MiCOM:s P140-relä saknar.

Den sjätte jämförelsen och analysen görs på *communication*-funktionerna som handhar konfigureringen av kommunikationen i reläet. Jämförelsen visar att ABB:s **DPU2000** är vinnare med 55 poäng. Orsaken till detta är att reläet erbjuder 32 reläer kopplade i daisy-chain samt har många protokoll och portar.

Den sjunde jämförelsen och analysen görs på *user interface* -funktionerna. Dessa funktioner behövs i kommunikationen mellan användaren och reläet. Jämförelsen visar att ABB:s relä **REF 541** är vinnare med 503 poäng. Orsaken till detta är att ABB:s REF 541 är försedd med en stor LCD som fungerar som användargränssnitt. Funktionen har hög prioritet p.g.a. de grafiska egenskaperna.

Den åttonde jämförelsen och analysen görs på *software support* -funktionerna. Dessa behövs för set-up och konfigurering av systemet via en PC. Denna kategori har ingen prioritetsskala då det endast finns en funktionskategori. Jämförelsen visar att vinnare är ABB:s **REX 521** och **REF 541**, eftersom dessa reläer har det högsta antalet SW-verktyg.

Den nionde och sista jämförelsen presenterar det totala antalet poäng för varje enskild underkategori. Jämförelsen visar att vinnare är ABB:s relä **REX 521**, med totalt 3658 poäng. Detta beror i huvudsak på underkategorin *post-fault analysis*.

I det vinnande reläet är *disturbance recording* -bufferten lång samtidigt som funktionen post-fault analysis har hög prioritet. På andra plats kommer MiCOM's **P140** relä. ABB:s reläer **DPU 2000** och **REF 541** finns på tredje respektive fjärde plats. På femte och sjätte plats återfinns MULTILIN's **SR750** och **SEL-351** och på sjunde plats finns Siemens **7SJ512**. Sist placerar sig SEL**-251** på en åttonde plats.

Det är en svår uppgift att jämföra olika reläer på ett objektivt sätt p.g.a. att en jämförelse kan baseras på olika aspekter t.ex. från användarens synvinkel, en ekonomiska synvinkel, en funktionell synvinkeln, en effektivitetssynvinkel o.s.v. Samma funktion kan få olika poäng beroende på vem som använder reläet. Några funktioner som idag får få poäng får kanske många poäng i morgon. I några länder kan en speciell funktion vara ett måste, emedan den inte behövs alls i ett annat land.

Allmän introduktion av MBS 1000

Den nya MBS 1000-systemet introducerar ett nytt sätt att tänka, ny teknologi, ny högre kvalitet på produkter, lösningar med dagens nya teknologi, utmaningar fokuserade på en ny generation och revolution av reläerna som berör både hårdvaran och mjukvaran.

Då MBS 1000 är ett *virtullt relä* så inladdas en ny funktion eller konfiguration i reläet. Funktioner kan laddas in i målreläet nästan var och hur som helst. Ytterligare finns det möjlighet att ladda konfigurationen, mjukvara och hårdvara som har ändrats i reläet tillbaka till funktionscentret.

Vi fann att *inte enbart mjukvaran utan även hårdvaran borde vara fritt konfigurerbar i RED 500.* Det krävs systemdimensioner som tillfredsställer många lösningar och tillämpningar med samma bashårdvara. Detta gör att antalet relätyper minskar.

I det nya relässystemet förbättras *bussarnas hastighet* och *svarstiderna reduceras.* Det är nödvändigt att kunna integrera *mjukvaruelement i hårdvaran* och utföra *konfigurationen på en visuell eller verbal nivå*.

MBS 1000 -reläfamiljen utför många kontroller, pollningar och kommandotolkningar från många enheter över en GIGA-bit buss med hög hastighet.

Vissa enheter utför själv grundläggande beräkningar och tolkningar av data och sänder sedan dessa data vidare för att, om nödvändigt, låta huvudenheten forsätta med dataprocessen.

Genast en helhetsfunktion avförts från ett relä tilldelas reläet en ny roll i systemet genom omkonfigurering. MBS 1000 -reläsystemet är ett dynamiskt system med tanke på tid, plats, tillämpning och funktionalitet.

För att koncentrera den information och kontroll som ett stort system tillhandahåller och upprätthåller med god översikt över systemet så behövs (globalt via Internet, n:te generationen av telekommunikation eller satellit) ett flertal högnivåbetjäningsenheter. Dessa enheter kan innehålla funktionsprocesserna för helhetssystemets hela huvuddatabas.

För att kunna ladda in ny HW, SW, dataelement o.s.v. som används i reläerna, måste huvudkretsen vara konfigurerbar. Det måste garanteras en hög processoreffekt, system- och datagenomströmning samt höghastighetsfjärrbussar. Systemet upprätthåller datakvaliteten genom kryptering av information, protokollhantering, matematiska algoritmer vid dataomvandling, datakompression och -dekompression, brandväggar, virusskydd, elektriska skydd och självövervakning.

För att få en snabb reaktion under uppstart efter underhållsstopp och pauser, skall systemet vara uppbyggt av inre kärnor som tillåter automatisk själv-set-up, artificiell intelligens, oskarp logik, eventuellt med neurala nätverk. Dessa attribut tillhör reläets **självkonfigureringsfunktioner**. Under konfigurering befinner sig reläet i baskonfigureringsmod.

Reläerna är bakåtkompatibla för kommunikation med äldre system, med kod och data, via kommunikationsbussar, gateways, translatorer inklusive realtids-översättare (motorer).

Under speciella förhållanden kan resultatet från signaleringen, informationsbehandlingen och systemet tvinga reläet att bli självständigt och ta eget ansvar. Även stöd måste kunna fås genom att övriga reläer deltar i kommunikationen som överför data och tar del i informationshanteringen. Det är då möjligt att använda en fjärrstyrningsbuss för processkontrollerad konfigurering av reläet.

Systemet håller linjen “operativsystemoberoende” och programmerare och användare kan använda ett flertal programmeringsspråk när de konstruerar HW/SW/data/kod för systemet. Det finns en generell programmeringsstandard som understöds av reläets språktolk. Denna genererar reläets eget lokala språk som exekveras i operativsystemet.

Konfigurationen kan ske lokalt eller globalt med hjälp av grafiska gränssnitt och displayer, vilka har setup-symboler och diagram men även stöd för kamera under konfigureringsproceduren.

Då användaren står i kontakt med setup-delen av reläerna, kan systemet **konfigureras virtuellt**. Även **verbal** konfigurering är möjlig då reläet eller systemet förstår och svarar på uttalade kommandon.

Alla system och reläer kan kopplas till ett eller flera internationella eller nationella kontrollcentraler varifrån operatören kan ha full överblick, inblick och kontroll över ett obegränsat antal reläer fritt valbara i grupper eller konfigurationer. Systemet erbjuder en världsomspännande full systemkontroll och ger vid behov användaren hjälp med konfigureringen. MBS 1000 erbjuder användaren interaktiv konfigurering.

Systemets basversion är konkurrenskraftig med tanke på priset. Systemets delenheter måste även ha ett konkurrenskraftigt pris. Ytterligare erbjuder systemet speciella lågprisproduktversioner. Dessa är speciella reläer med låga produktions- och systemkostnader vilka har en begränsad funktionalitet.

MBS 1000-systemet inkluderar i huvudsak tre huvudfamiljer (SERVER-, CONTROLLER- och MONITOR-familjen), vilka är indelade i grupper med olika service- och kemplexitetsnivå. Dessa familjer kan även indelas i underfamiljer. Huvudfamiljerna i MBS 1000 kan indelas i följande grupper:

- **MBS 11xx**, som hör till *SERVER-reläfamiljen* på *basnivån* och har funktionskombinationer med 3 analoga ingångar och 4 digitala utgångar.

- **MBS 13xx**, som hör till *SERVER-reläfamiljen* på *mellannivån* och har funktionskombinationer med 4 analoga ingångar och 4-5 digitala utgångar.

- **MBS 15xx**, som hör till *SERVER-reläfamiljen* på *hög nivå* och har funktionskombinationer med 5 eller flere analoga ingångar och 5 eller flere digitala utgångar.

- **MBS 17xx**, som hör till *SERVER-reläfamiljen* på den *utökade högre nivån* eller *CONTROLLER-reläfamiljen* på *basnivån.* Denna grupp av reläer har även speciella lösningar som inte finns med i de övriga SERVER-reläfamiljerna.

- **MBS 19xx**, som hör till *CONTROLLER-reläfamiljen* på *mellannivå och hög nivå.* Denna ansvarar för signaleringen mellan relägrupperna MBS 11xx och 17xx. Relägruppen MBS 19xx-gruppen som har den största funktionkomplexiteten och högsta intelligensen i MBS 1000 -reläfamiljen.

- För *övervakning* och *kontroll* används **PC-enheter** i huvudkontroll-och övervakningscentralen. Dessa PC (som representerar *MONITOR-familjen*) övervakas av en eller flere operatörer t.ex. i en station, som kontrollerar ett stort antal reläer kopplade till nätverket. I några fall kan denna funktion även överföras till en annan typ av enheter i hierarkin.

Avslutning

Resultatet av dynamiken i MBS 1000-systemet är att inte endast systemet utan även dess moduler fritt kan omplaceras.

Medan prototypen planeras och skapas faller irrelevanta förslag och lösningar ofta bort samtidigt som vi håller motivationen på hög nivå. Nya intressanta lösningar, som senare tas med i den första riktiga produkten kan ändå uppstå.

När det nya MBS 1000-systemet är genomfört kommer vi att snabbt kunna skapa nya funktioner och lösningar som inte kräver en lång utvecklingstid, vilket tidigare var fallet då hårdvaran och mjukvaran till ett system planerades och implementerades. Vi får därigenom mera tid för själva kunden.

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ABBREVIATIONS USED

Abbreviation	Explanation
ABB	Asea Brown Boveri
MMI	Man Machine Interface
MCPU	Main Central Processor Unit
LCD	Liquid Crystal Display
OTPROM	One Time Programmable Read Only Memory
RAM	Random Access Memory
EEPROM	Electrically Erasable Programmable Read Only Memory
PLD	Electrical Programmable Logic Device
A/D	Analog/Digital
PC	Personal Computer
BDM	Background Debugging Mode
JTAG	Joint Test Action Group
CAN	Controller Area Network
PCB	Printed Circuit Board
pROBE+	Software running at the target board giving debugging service to XRAY software running in the PC
XRAY	Software running in the PC giving debugging service to the user and +pROBE software running at the target board
ASIC	Application Specified Integrated Circuit
FPGA	Field Programmable Gate Array
VHSIC	Very High Speed Integrated Circuit
poss.	possible
etc.	et cetera
no.	number of
ch.	channel

OTHER EXPRESSIONS AND THEIR EXPLANATIONS

MiCOM	Company structure based on GEC, England, ALSTOM France, AEG, Germany and SIR, Italy.
SIEMENS	Company from Germany
SEL	Schweizer Engineering Laboratories
MULTILIN	Company structure based on General Electrics, USA and Multilin, Canada.
SEG HIGH	Schaltanlagen-Elektronik-Geräte (SEG).
TECH LINE	Company from Holland.
COMSYS	Common System
SRIO xx00	Central unit e.g. SRIO 500 controlling and reading information from a group of relays capable of forwarding information or reacting on messages.
A/D converter	Circuit that converts an analog input value into a digital output value.
Trip	Activation of the event stage
Earth fault	Function reacting on short circuit (0 – 3 kohm) between phase and earth. Generates a trip.
Phase overcurrent	Function reacting on overcurrent in a phase.
Directional overcurrent.	Function reacting on the direction of the overcurrent.

Sensitive earth fault	Function reacting on short circuit generated e.g. by a falling tree (impedances from 3 to 10 kohm). Generates a trip or an alarm.
Very sensitive earth fault	Function reacting on short circuit generated e.g. by a falling tree (impedances from 10 to 100 kohm). Just generates an alarm.
Directional earth fault	Function giving information about the direction of an earth fault current.
Directional sensitive earth fault	Function giving information about the direction of a sensitive earth fault current.
Wattmetric characteristic	Function giving information on active or reactive power components.
Restricted earth fault	Function reacting on currents measured of both I_0 and phase I_{1-3} taking care of situations with transformer unbalance load.
Negative sequence overcurrent	Function reacting on negative sequence overcurrent. Reacting if the phase currents are not equal.
Voltage controlled overcurrent	Function reacting on overcurrent based on the actual phase voltage.
language motor	Explanation of a local compiler taking care of the common code written for all relay members and interpreting it for the local relay's processor code that executes it.
Undercurrent	Function reacting on too low a current flowing in a phase.
Residual voltage	Function reacting on residual voltage in the phases.
Undervoltage	Function reacting on too low a voltage in a phase.
Overvoltage	Function reacting on too high a voltage in a phase.

Thermal protection	Function operating as thermal protection.
Negative sequence overvoltage	Function reacting on negative sequence overvoltage.
Underfrequency	Function reacting on underfrequency measured in a phase.
Overfrequency	Function reacting on overfrequency measured in a phase.
Broken conductor detection	Function reacting on a broken line.
IEC IDMT CURVES	Function including tripping based on an inverse curve instead of a defined time in seconds.
IEEE/ ANSI CURVES	Function including tripping based on an inverse ANSI curve instead of a defined time in seconds.
Customisable curves	Function including tripping based on inputs by the customer (customer-based curve) instead of a defined time.
Cold load pick-up	Function enabling other types of setup when a motor is cold started.
Programmable scheme logic	Function allowing the user to program his own function scheme for the relay.
Auto-reclose	Function enabling autoreclosing if a short circuit is present for a short time and then disappears.
Check Synch	Function enabling the relay to check the synchronism of several networks.
CB control	Function enabling the control of a Circuit Breaker outside the relay.

Programmable logic inputs	Function enabling programming inputs after a special logic.
Programmable logic outputs	Function enabling inputs to be programmed according to a special logic.
Setting group	Function enables different setting groups to be used and changed.
Load shedding and restoration	Function reacting on falling load and fast load restoration.
Currents (Fundamental)	Function measuring phase currents on the phases.
Voltages (Fundamental)	Function measuring phase voltages on the phases.
Currents (RMS)	Function measuring currents (RMS) on the phases.
Voltages (RMS)	Function measuring voltages (RMS) on the phases.
Active power	Function measuring active power on the phases.
Reactive power	Function measuring reactive power on the phases.
Apparent power	Function measuring apparent power on the phases.
Power factor	Function measuring phase power factor.
Frequency	Function measuring frequency on the phases.
Rolling demand	Function measuring current values during a specific time with one minute between samples, resulting in an average value during the period measured.

Peak Demand phases.	Function measuring current values during a specific time with one minute between samples, resulting in one top value during the period measured.
Energy	Function measuring energy on the phases.
Power quality	Function measuring power quality on the phases.
IRIG-B	Function enabling time synchronisation of the relay via a satellite.
Fault records	Function performing fault recording.
Event records	Function performing event recording including all phase currents, I_0, start duration (%) of the tripping stage, etc.
Disturbance records	Function performing disturbance recording.
Fault locator	Function performing fault location.
Power-on and self monitoring	Function performing power-on and self-monitoring.
VT supervision	Function performing Voltage Transformer supervision.
CT supervision	Function performing Current Transformer supervision.
Sensor inputs	Function enabling sensor checking.
CB failure	Function indicating a fault in the Circuit Breaker
Signalling supervision	Function enabling signal supervision (if there are signals)
Trip circuit monitoring	Function performing circuit monitoring.
Trip circuit supervision	Function performing circuit supervision.

CB condition monitoring	Function performing CB condition monitoring.
Ports	Function performing communication port's set up.
Protocol	Type of protocol used in the communication with the relay
No. of relays in daisy chain	Setup of relays connected together into the daisy chain (the same communication network).
DIAGNOSTICS	Function allowing the relay to perform self-supervision.
n character display	Number of characters per line in the display to help the relay user.
LEDs	Number of LEDs on the display to help the relay user.
No. of default messages	Setup of the number of default messages in the relay.
SOFTWARE SUPPORT	Software support available around this unit/ relay and relay system
hardsoftware	Software usually executed in the processor, replaced by FPGA, ASIC-circuits or hardware.

APPENDIXES

APPENDIX 1. Protection functions in different relay manufactures.

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
PROTECTION								
Phase overcurrent	YES	YES	YES	YES	YES	YES	YES	YES
Directional overcurrent	NO	YES	YES	YES	(YES)	NO	YES	YES
Earth fault	YES	YES	YES	YES	YES	YES	YES	YES
Sensitive earth fault	NO	NO	NO	YES	YES	NO	NO	NO
Directional earth fault	YES	YES	YES	YES	(YES)	NO	YES	YES
Directional sensitive earth fault	NO	NO	NO	YES	(YES)	NO	NO	NO
Wattmetric characteristic	NO	NO	NO	YES	NO	NO	NO	NO
Restricted earth fault	NO	NO	NO	YES	NO	NO	NO	NO
Negative sequence overcurrent	YES	NO	YES	YES	NO	YES	YES	NO
Voltage controlled overcurrent	NO	NO	NO	YES	NO	NO	YES	YES
Undercurrent	NO	NO	NO	YES	NO	NO	NO	NO
Residual voltage	YES	YES	NO	YES	NO	NO	NO	YES
Undervoltage	NO	YES	YES	YES	NO	NO	YES	YES
Overvoltage	NO	YES	YES	YES	NO	YES	YES	YES
Thermal protection	YES	YES	NO	YES	YES	NO	NO	NO
Negative sequence overvoltage	NO	NO	NO	YES	NO	NO	NO	YES
Underfrequency	YES	NO	YES	NO	NO	NO	YES	YES
Overfrequency	YES	NO	YES	NO	NO	NO	YES	Monitoring
Broken conductor detection	YES	NO	NO	YES	NO	NO	NO	NO
IEC IDMT CURVES	YES	YES	YES	YES	YES	NO	YES	YES
IEEE/ ANSI CURVES	NO	NO	(YES)	YES	NO	YES	YES	YES
Customisable curves	NO	NO	YES	NO	NO	NO	NO	YES
Cold load pick-up	NO	NO	YES	YES	NO	YES	YES	YES

Table 18. Complete protection function table of the relays compared ****.

****) I am grateful to Henrik Sundell for letting me use this table.

APPENDIX 2. Control and measurement functions in different relay manufactories.

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
CONTROL								
Programmable scheme logic	(YES)	YES	YES	YES	NO	YES	YES	YES
Auto-recloseing	YES	YES	YES	(YES)	YES	YES	YES	(YES)
Check Synch (Synchrocheck)	YES	NO	NO	(YES)	NO	NO	(YES)	(YES)
CB control	YES	YES	YES	YES	YES	YES	YES	YES
Programmable logic inputs	9	15/25/34	13	8/(16)	2	6	8	14
Programmable logic outputs	6	12/18/26	8	7/(14)	5	4	11	8
Setting group	2	2	1	4	1	6	6	1
Load shedding and restoration	NO	NO	YES	NO	NO	NO	YES	YES

Table 19. Complete control function table of the relays compared ****.

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
MEASUREMENTS								
Currents (Fundamental)	YES	YES	YES	YES	YES	YES	YES	YES
Voltages (Fundamental)	YES	YES	YES	YES	YES	YES	YES	YES
Currents (RMS)	YES	YES	NO	YES	NO	NO	YES	NO
Voltages (RMS)	YES	YES	NO	YES	NO	NO	YES	YES
Active power	YES	YES	YES	YES	YES	NO	YES	YES
Reactive power	YES	YES	YES	YES	YES	NO	YES	YES
Apparent power	YES	YES	NO	YES	YES	NO	NO	YES
Power factor	YES	YES	YES	YES	NO	NO	YES	YES
Frequency	YES	YES	YES	YES	NO	YES	YES	YES
Rolling demand	YES	YES	YES	YES	NO	YES	YES	YES
Peak Demand	YES	YES	YES	YES	NO	YES	YES	YES
Energy	YES	YES	YES	YES	NO	NO	YES	YES
Power quality	YES							

Table 20. Complete measurement functions table of the relays compared ****.

APPENDIX 3. Post-fault analyse and monitoring functions in different relay manufactories**.**

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
POST-FAULT ANALYSIS								
IRIG-B	NO	NO	NO	(YES)	NO	YES	YES	(YES)
Fault records	YES	YES	32	5	3	YES	YES	YES
Event records	50	YES	128	200	YES (no details)	12	YES	100
Disturbance records	12...1066 c, depending on records & channels		1 record of 1.5 s	20 records @ 10.5s, 12 samples per cycle		12 records 11 cycles	YES 15 records 30 cycles 16 s/c	1 record 265 samples 16 samples / cycle
Fault locator	YES	YES	YES	YES	NO	YES	YES	YES

Table 21. Complete post-fault analysis function table of the relays compared ****.

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
MONITORING								
Power-on and self monitoring	YES	YES	YES	YES	YES	YES	YES	YES
VT supervision	YES	NO	NO	YES	NO	NO	YES	YES
CT supervision	YES	YES	NO	YES	NO	NO	NO	NO
Sensor inputs	YES	YES	NO	NO	NO	NO	NO	NO
CB failure	YES	NO	YES	YES	YES	YES	YES	YES
Signalling supervision	NO	NO	NO	YES	YES	NO	NO	NO
Trip circuit monitoring	YES	YES	YES	(YES)		(YES)	(YES)	NO
Trip circuit supervision	YES	YES	YES	NO	NO	NO	NO	NO
CB condition monitoring	YES	NO	NO	YES	NO	YES	YES	YES

Table 22. Complete monitoring function table of the relays compared ****.

APPENDIX 4. Communication, user interface and software support functions in different relay manufactories.

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
COMMUNICATIONS								
Ports	RS 232, Fibre optic	RS 232, RS 485, Fibre optic	RS 232, RS 485, Fibre optic	RS232, RS485	V.24 , RS 485, Fibre optic	RS232	RS232	RS485, RS422, RS232
Protocol	(LON Bus) SPA Bus IEC - 103	LON Bus SPA Bus VDEW6	SPA Bus MODBUS INCOM	Courier, Modbus, IEC -103	VDEW	ASCII	(DNP3.0) ASCII	Modbus
No. of relays in daisy chain			32 for RS485	32	1	1	1	32
DIAGNOSTICS			YES	YES	YES	YES	YES	YES

Table 23. Complete communication function table of the relays compared ****.

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
USER INTERFACE								
n character display	2 x 16	Large LCD	80	2x16	32	NO	20	40
LEDs	3	13	13	(3-5)	8	8	16	20
No. of default messages			1	4+8	Unknown	NO	16	20

Table 24. Complete user interface function table of the relays compared ****.

FUNCTIONs	ABB REX 521	ABB REF 541	ABB DPU2000	MiCOM P140	SIEMENS 7SJ512	SEL-251	SEL-351	MULTILIN SR750
SOFTWARE SUPPORT	CAP 501, LNT, LIB 500/510	CAP 501, LNT, LIB 500/510	ECP / CurveGen	MiCOM S1, PAS&T	DIGSI	SEL-Logic SEL 5016	SEL 5010	760SETUP

Table 25. Complete software support function table of the relays compared ****.