100 years of relay protection, the Swedish ABB relay history

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INTRODUCTION

The ABB relay protection and substation automation history goes back to the turn of the previous century. The first protection relay type TCB was developed in the early years of 1900. The first installation was made in 1905. By 1925, a remote controlled station was put into operation. ABB has delivered many millions protection and control devices throughout the world. Through the years ABB has introduced a great number of leading innovations within the protection and control field. The development was from the beginning made with a national perspective, but very early a global perspective was introduced when designing relay and control equipment. The development can be divided in three main stages; the first stage was the era of electromechanical relays, which started over 100 years ago. The next era was static or electronic relays, which were introduced in the 1960s. The present era with microprocessor based relays started in the beginning of the 1980s, where microprocessor performed the logics, but the filtering was analogue. The first fully numerical relay was introduced 1986.

1. GENERAL

The technological history in Protection and Station Automation can be shown comparing space requirements between modern and old equipment. One numerical terminal can replace up two five panels with electromechanical relays or two panels with static relays. Self-supervision and communication are additional features of numerical terminals


Comparison of equipment from 1925 and 1994.

2. HIGHLIGHTS OF ABBs RELAY DEVELOPMENT

- <1905 Overcurrent trip devices, built-in in HV-breakers
- 1905 First time-overcurrent relay
  1920 RI relay
- 1925 First ABB remote control station
- 1930 First plug-in relay modular system type RR
- 1940 mho Distance relay,
- 1940 Harmonic restraint transformer-differential
- 1950 Compensator poly-phase distance relay
- 1960 Analogue electronics was introduced
- 1964 First solid-state relays
- 1968 Microprocessors introduced
- 1969 COMBIFLEX plug-in system, COMBITEST
- 1970 Static ultra-high-speed bus differential relay
- 1974 Static distance relay for EHV/UHV applications using sequential logic circuits
- 1976 Static ultra-high-speed line protection relay
- 1978 Solid-state timer relay using customised LSI chip
- 1980 Solid-state distance relay using PROM chip
- 1981 Microprocessor-based line protection
- 1982 Microprocessor-based fault locator
- 1983 Microprocessor-based station control system
- 1983 Computerised analogue Power-system Simulator
- 1986 First fully numerical line distance terminal
- 1994 Numerical terminals, Series 500, introduced
- 1996 New Training Centre opened
- 1999 Inauguration of ABB Simulation Centre for product verification, with numerical real-time power system simulator.

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3. ELECTROMECHANICAL RELAYS

A large number of various types has been developed and manufactured by ABB. Only some examples can be described.
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The first relay functions were integrated in the breaker design, and acted as overcurrent trip. Below, a design from the beginning of the previous century is shown. This design was used in the first hydro power stations as early as the end of the 19th century.
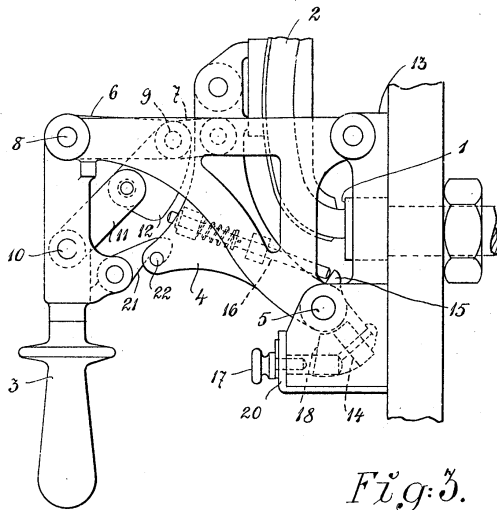
Overcurrent trip mechanism from the beginning of 1900

The first stand-alone electromechanical relay was designed 1904. The first relay was produced 1905. The relay had bellow made of impregnated balloon cloth, which in combination with an air valve attenuated the movement of a solenoid to give the required delay. This design was used in many installations, although the ageing of the textile bellow gave some problems.
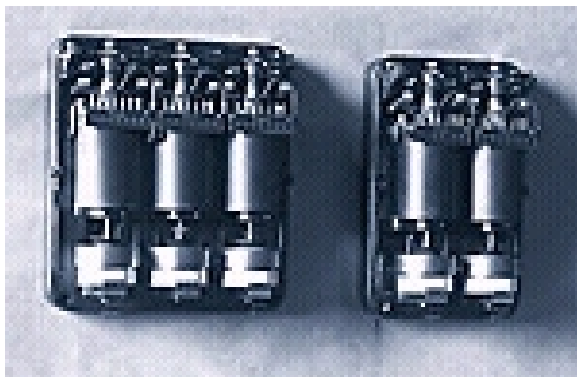
The first time-overcurrent relay made by ABB, type TCB, manufactured 1905

ABB first relay of induction type was delivered 1912 to a hydropower station in the north of Sweden, built to deliver power at 16 2/3 Hz to the railway from Kiruna to Luleå, which was built to transport iron ore. This was the first electrified railway in Sweden.

Thermal relays.
The first thermal relay, type designation RW was delivered 1917, and was used for three-phase motors. The design was based on the bimetallic principle, i.e. the difference in thermal elongation for two metals.

Thermal relay type RWE

In 1918, the first special relay department in ABB (ASEA) was formed under the management of a very famous relay designer, W H Petersén. The most famous relay from this era is the RI relay.

RI relay
The RI relay was designed in 1918 and delivered in many countries from 1920 to 1985, when the last relay was manufactured. However, this relay is still used in many countries. Actually, the time overcurrent RI curve is also implemented in modern numerical relays for co-ordination of RI relays still in service.
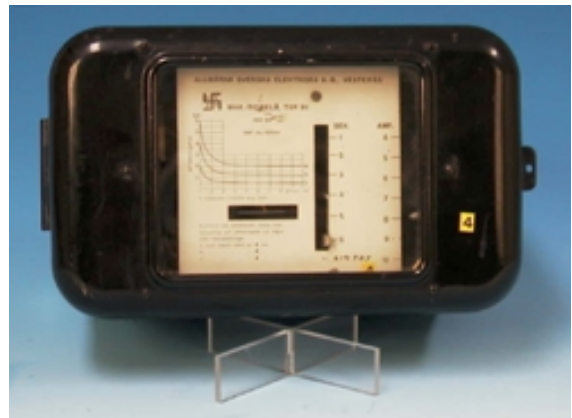

Figure 4. Induction type time over-current relay type RI from 1920

From the era 1920 to 1930 a large number of various relays were introduced. Some examples can be given.
- Sensitive earth-fault protection type RIRA 3
- Power relay type RPB 10
- Balance relay, differential protection type RBF 5
- Poly-phase power relay type RPAF
- Voltage regulation relay type RCA
- Delayed under voltage relay type RODA
- Frequency relay type RF 2
- Thermal relays type RTV
- Earth fault relay type RJMS 1
- Signalling relays
- Timers

Earth fault relays

ABB designed already 1924 a sensitive directional earth fault protection electrodynamic relay type RMSS with 0,1 VA burden. This relay was replaced 1938 with an even more sensitive earth fault relay type RIRA, mainly used for hydropower generators. The burden was 0,001 VA

Balance relays

The first balance relays type RBD for Ac was designed 1925, and was used as differential protection for transformers and generators

Power relays

In 1917 also the first power regulation system was introduced. The first power relays of induction type was introduced 1924, type RE

Voltage regulation relays

An induction relay for voltage regulation of transformers with tap changers was introduced around 1925, type RCA and RCE (RRCE for plug-in system RR)
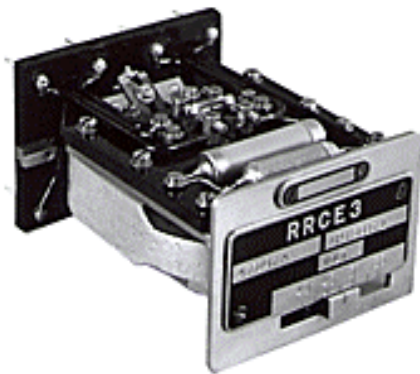
Instantaneous current and voltage relays

Around 1930 a series of instantaneous maximum and minimum current and voltage relays were introduced, type RMJ. In the same year the world's first modular relay system type RR was introduced. The RMJ was redesigned for the modular RR system with type designation RRMJ
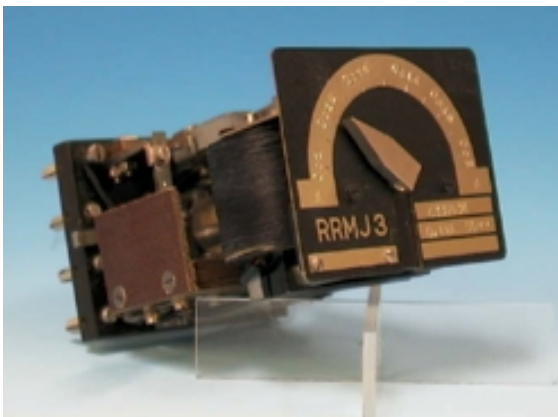
Instantaneous overcurrent relay type RRMJ

Electromechanical line distance relays

Line distance relays were introduced in the 1940s. They represented state of the art in the electromechanical era. The distance relay type RYZK was introduced in the 1950s. The last relay was manufactured 1985 and is still in use in many countries.
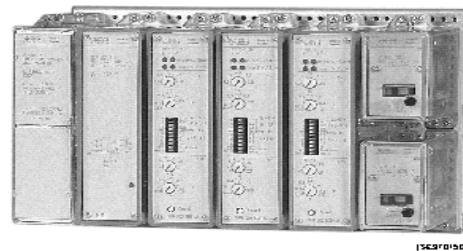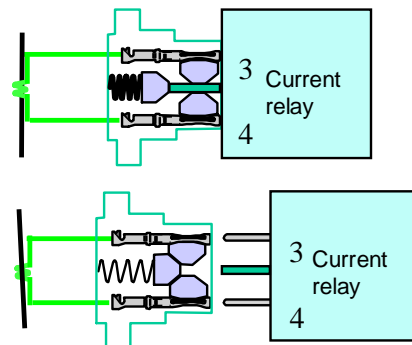

Line distance relay type RYZKC

4 STATIC RELAYS

Combiflex relays and modular building system

The previous modular plug-in system type RR was replaced by the Combiflex system 1960. In the beginning the relays was electromechanical, then static and now microprocessor have been introduced. The first static electronic relays was introduced in the Combiflex range, in the form of timers, time overcurrent relays, voltage relays etc. and later also a number of high performance static electronic protection devices was introduced. The first Combiflex static relays were introduced 1969


Combiflex assembly.

Combiflex short-circuiting connector for AC- current inputs

A modern Combiflex rely type RXHL411 non-directional overcurrent protection

Line distance relays

The worlds first line distance relay with quadrilateral characteristic, type RAZOG was introduced in 1970. This characteristic was possible to implement using static electronics. The RAZOG was a three-phase switched scheme static relay, suitable for the protecting of overhead lines and cables. The shortest operate time was 21 ms. The operating range in the impedance plane had the appearance of a tetragon, which gave much better resistive coverage then the previous electromechanical mho-relays
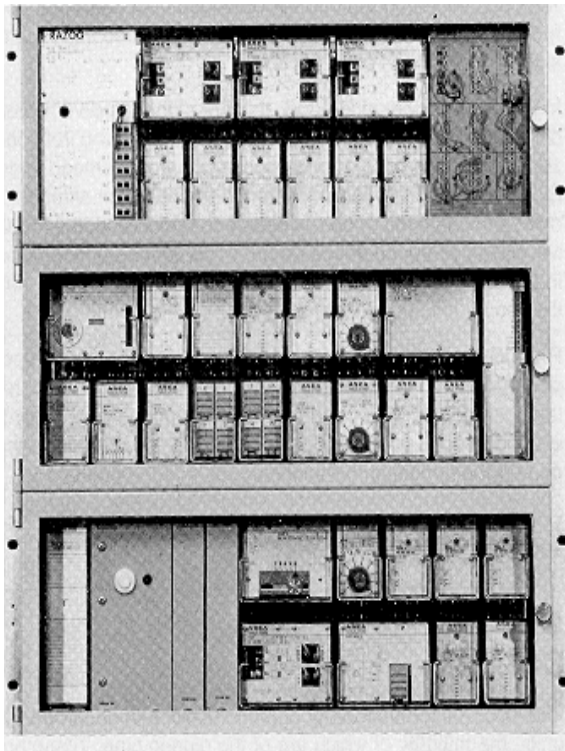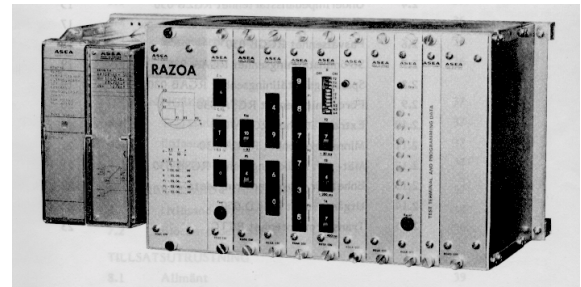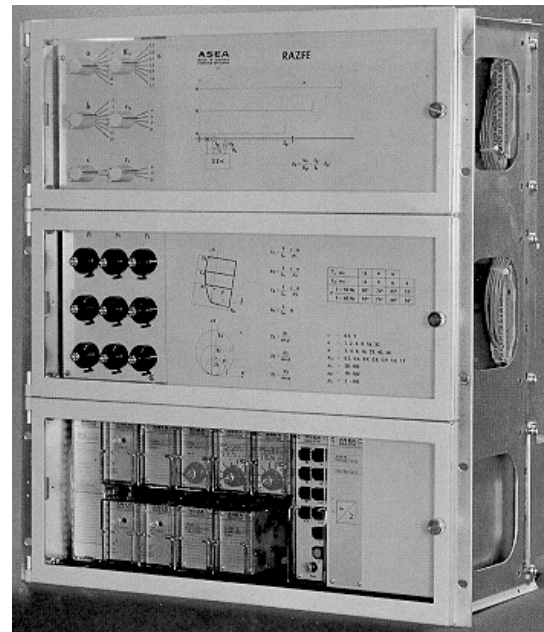

RAZOG line distance relay
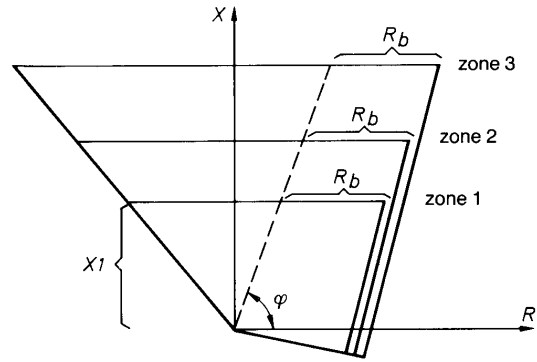
The quadrilateral characteristic of RAZOG

A very successful line distance relay for subtransmission was a so-called switched scheme relay type RAZOA, which was introduced in 1976.

RAZOA Switched scheme line distance relay

State of the art in static distance relaying can be represented by the so-called full scheme distance relay type RAZFE, which was introduced in 1975

RAZFE full scheme line distance relay

4

Ultra high speed relaying

Ultra-high-speed (UHS) relays with operate time of one quarter cycle to a half cycle, began with the RADSS bus differential relay, introduced in 1970.

The RADSS relay use what can be called a medium impedance measuring principle with extremely high security and dependability and very low requirements on the current transformers. A saturation time of less then 2 ms is satisfactory for correct operation More the 10000 busbar protection type RADSS has been delivered world-wide, and is still the standard busbar protection in many utilities


RADSS busbar differential relay

A novel approach on Ultra high-speed line distance protection was introduced 1976 with the travelling wave detector relay type RALDA. The directional wave detector measures only the sudden change in voltage and current. The relative polarities of the voltage and current change "waves" are compare to determine the direction of the fault. The concept has been used in many applications, especially for series capacitor lines, where conventional distance relays has limited functionality.
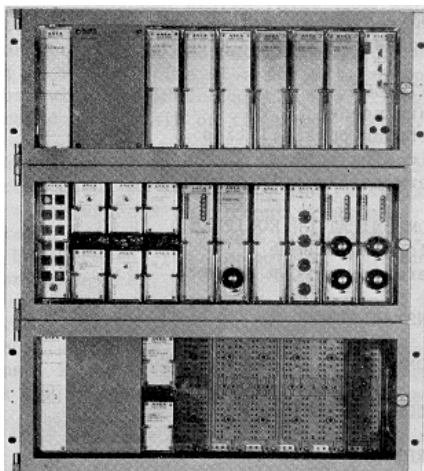
RALDA travelling wave relay
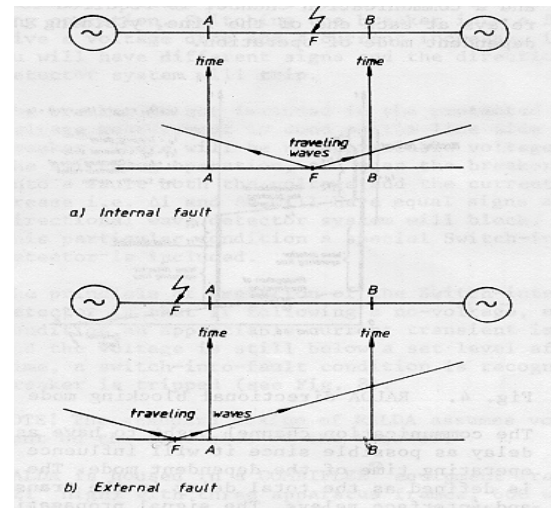
RALDA Travelling wave principal

Power system simulation

In 1985 the traditional power system simulator with physical models of the High voltage object was replaced with a hybrid computer controlled power system simulator.

Low level electronic analogue models represent the power system circuits and equipment, including the current and potential transformers, which feed the relays under test via high power amplifiers. The relay outputs trip and reclose miniature breakers, just as HV breakers do in actual service. The interaction between the power system and the relay under test can thus be simulated in real time, exactly as in actual service. This is the most important feature of an analogue power system simulation

In 1999 the analogue simulator was replaced by a fully numerical simulator. The mathematical power system models, such as lines, transformerers etc are excecuted in real time by a powerful supercomputer type HP 9000.

4 MICROPROCESSOR BASED RELAYS

Microprocessor based relays started to replace static relays in the beginning of the 1980s. At first it was "hybrid" solutions, where the time critical filtering was performed with analogue electronics. Typical examples are
REZ 1- Universal phase and ground distance relay for permissive and blocking schemes, 1-4 directional zones

RACID- Universal phase and ground overcurrent relay for lines and cables. Instantaneous, time delayed and start function is included. Time delayed function is programmable for definite time, normal inverse, very inverse and extremely inverse. RACID can display information about faulted phase, fault

REG 100- multifunction generator protection relay, with differential, underimpedance, overexcitation, overvoltage and other protection functions

REB 100- busbar protection with the same analogue measuring principle as RADSS, with an electronic comparator to reduce the current transformer

requirements by reduced power consumption with reference to the measuring circuit and with microprocessor logic and supervision

RACID Three- phase time overcurrent relay with phase- and earth fault overcurrent was introduced 1981


RACID Microprocessor time overcurrent relay

RACIF- is a low-power version of RACID and it performs the same protection functions. This relay does not need auxiliary power supply since it is self-powered from the CT's. An electromagnetic indicator stores phase and trip indications also after loss of power supply.
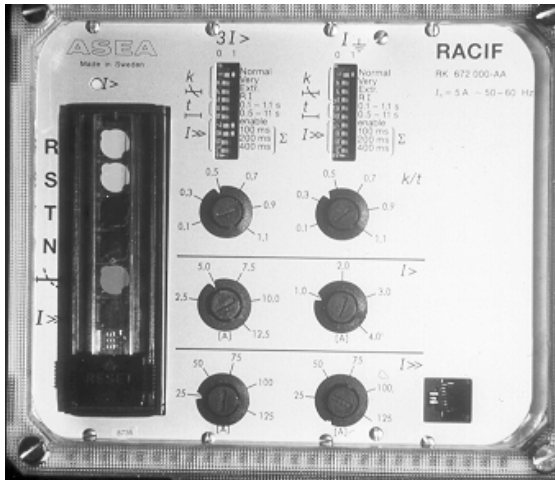
RACIF power supply independent three-phase and ground overcurrent relay

Fault localisation

The fault localisator RANZA was introduced 1983. In RANZA for the first time a truly numerical approach was used to calculate the distance to fault. The measuring signals were stored in a memory and the a system algorithm was used to calculate the distnce3 to fault with a much better accuracy, +- 2 %, than was previously possible with analogue electronics. The measuring principle is shown below.
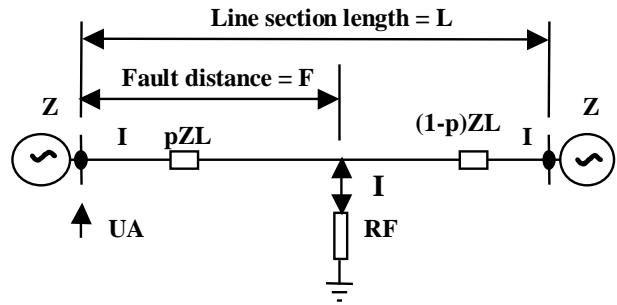
RANZA fault locator measuring principle

Numerical line distance protection

The world's first fully numerical line distance protection terminal, RELZ 100 was introduced 1986. This was also the first multifunction relay, where a number of functions were integrated.

- Full scheme line distance relay with 5 zones
- Load compensated operation
- Phase selector
- Power swing blocking
- Disturbance recorder- 1 ms resolution
- Event recorder
- Over-current
- Fault locator
- Built-in protection communication schemes
- Serial data communication with two ports for monitoring and control
- etc

RELZ 100 Line distance terminal

5 NUMERICAL PROTECTION AND CONTROL CONCEPT SERIES 500

The 500 series protection and local control terminals were introduced 1994. To really take advantage of the modern microprocessor technology, the 500 series of microprocessor based protection and control equipment has been designed with a platform concept. The platform consists of a number of hardware modules for analogue inputs and A/D conversion, a main processing module, dc/dc supply module and a number of flexible input and output modules. Communication modules, for example a 56/64 kbit communication module for differential protection is also included in the platform. The platform incorporates an extensive library of

protection and control software functions, monitoring functions and communication functions.

Thus**,** it is **technically possible to integrate the protection and control functions**, for example in a bay terminal for a power line. It is easy to see that the different control and protection functions are using the same information from the primary equipment and have many similarities, or that some functions are redundant. By co-ordinating these main functions and integrating them when possible, the functionality and performance of the control and protection system can be increased. The integration can both decrease the required wiring and space and increase the overall reliability and availability together with reduced investment and operation cost. Of paramount importance is then how the basic power system requirements on dependability, security, fault tolerance and availability can be achieved.

### *Series 500 object terminal concept*
The designation *terminal* is used instead of relay, protection or control device, since today many functions can be integrated in the terminal. Thus, the terminal can be used as a line protection terminal with ancillary functions. It can also be used as terminal for local control or as an object terminal, where both control and protection, etc. is included as an **object terminal.** or co-ordinated in various degrees for automated substations, or as replacement for conventional centralised RTUs standard PC or telephone modem, without the need for additional equipment. Various software programs, such as REVAL disturbance evaluation, RCALC setting calculation and RESDA Expert programs in Windows will furthermore enhance the capability of the information handling

Hardware modules
The basic object terminal is provided with a CPU module and DC/DC converter. In addition a number of various input and output modules can be installed in the terminal. The number of modules depends on the size of the mechanical housing. The housing can be a 1/2, 3/4 or 1/1 19" rack, 6 U high (247 mm) with depth 245 mm

Functional library
The terminals can be loaded with a number of modular, type tested software function blocks as shown below
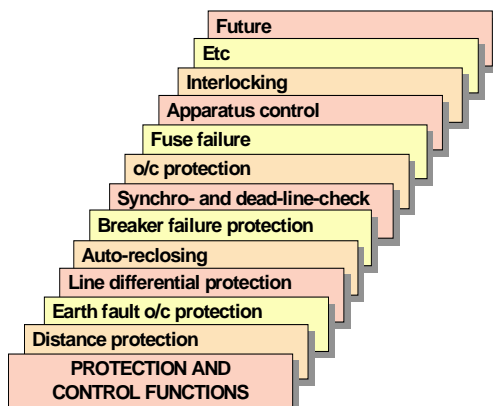
Protection and control functions
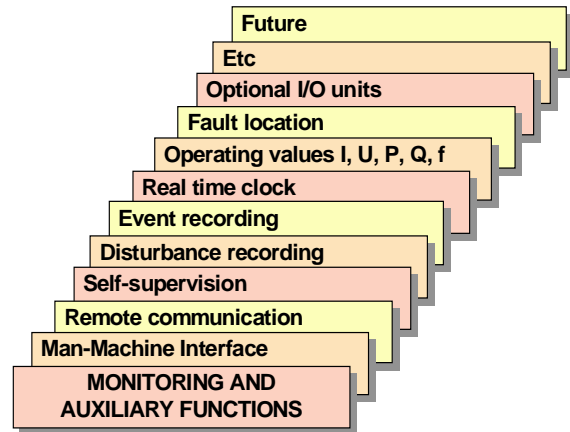
Monitoring and auxiliary functions
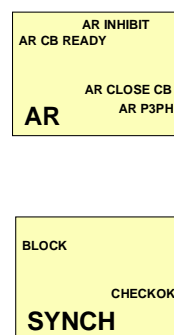
Functional configuration
The various functions are arranged as individual blocks, that can be combined either as predetermined schemes or custom designed utilising function block programming. This means that an output signal from one function can be used as an input signal to another function. These function blocks include all protection functions, tripping and autoreclosing logic, all control functions for apparatus control and interlocking, binary inputs and outputs as well as a logical function library with AND, OR and Time Delayed elements (0-50 seconds with 5 ms resolution).

As an example each distance zone can be programmed individually and also accessible individually in the logic. External (or internal) signals can be used to block or enable the auto reclosure.
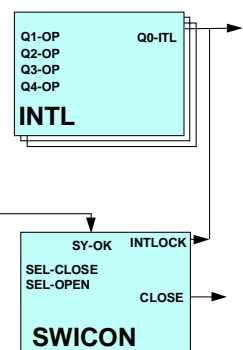
The Configuration can be made according to the application requirements

The protection and control functions can be integrated in the terminal in a very cost efficient way

Co-ordination of protection and control functions

To allow the user to take advantage of the configuration flexibility, a **C**omputer **A**ided **T**ool (**CAP 535**) for PC is available.

The tool **CAP 535** is based on the IEC standard 1131-3, and allows the user to configure the terminal using graphic symbols, which makes the handling of the configuration tool very simple

6 THE 500 SERIES TERMINALS

The first terminals in series 500 were introduced in 1994. The terminals could perform both protection and control functions. A large functional library is available. Some examples:

- Three/four/five zone distance protection
- General fault criteria
- Three-phase trip
- High set inst. O/C protection
- Scheme communication
- Fuse failure supervision
- Switch-onto-fault facilities
- Four parameter setting groups
- Restricted settings by local HMI or BI
- Local information on:
  - Service value of I, U, P, Q, f, R, X
- Status of I/Os and internal logics
- Fault locator with U&I phasors
- Stub protection
- Under- and overvoltage protection
- Breaker failure protection
- Event recorder
- Disturbance recorder
- Automatic reclosing-1/3 phase
- Up to 3/6 I/O modules
- Synchro check, energising check and phasing
- On line control functions
- Simulation logics
- System supervision functions
- - overload
- - broken conductor
- - loss of voltage
- Remote serial communication
- PC programs for information handling
- etc

Line distance terminals
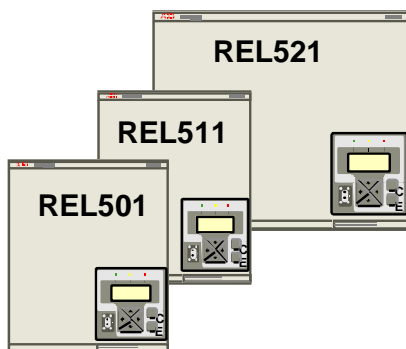
REL 501 Line distance terminal for distribution
REL 511 Line distance terminal for subtransmission
REL 521 Line distance terminal for transmission

The characteristic is shown below
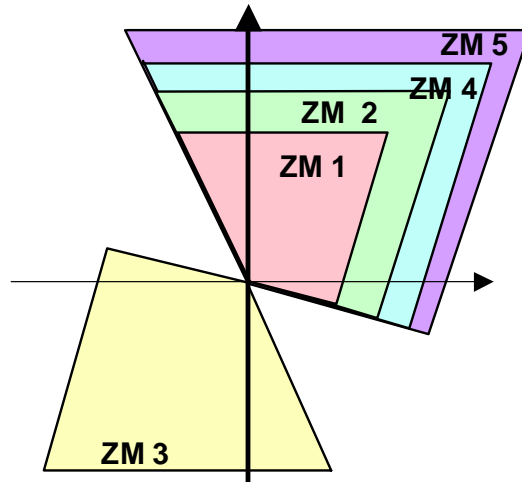
1996 a high speed distance terminal REL 531 was introduced. The high speed distance algorithm is based on ΔI and ΔU. Together with a very fast phase selector based on the same principle as RALDA travelling wave detector, single phase tripping time < 1 cycle is achieved
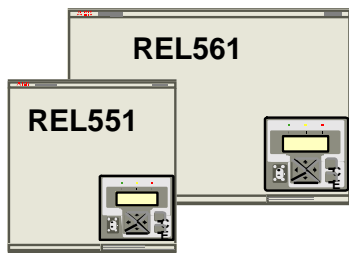

REL 531 High speed distance protection
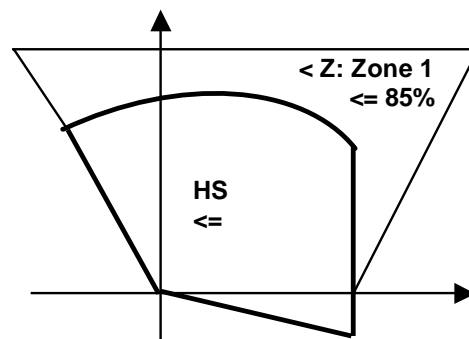
REL 531 characteristic

Line differential terminals
Also in 1994 a new concept for differential relaying was introduced. The communication between the terminals was utilising 56/64 kbit digital telecommunication, replacing the previous pilot wire relays.
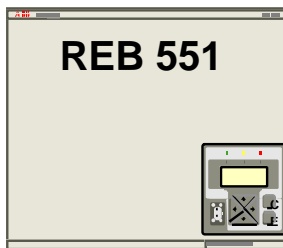
REL 551 Line differential terminal with current functions

REL 561 Line differential terminal with current and voltage functions. (Distance back-up available)

A breaker terminal was introduced 1994. The breaker terminal cointains breaker oriented functions

- Auto reclosure,
- Synchro check,
- Breaker failure etc

REB 551 Breaker terminal

In 1996 a dedicated control terminal REC 561 was included in the 500-series. This terminal has control oriented functions

- Control of up to 12 bays / 24 apparatuses
- Interlocking
- Synchro- check and energising
- Auto-reclosing of up to 12 breakers
- Configurable logic
- Pole discordance protection
- Fuse failure protection
- Breaker failure supervision
- Loss of voltage supervision
- Disturbance recorder
- etc

REC 561 Control terminal

Transformer terminal

In 1998, a transformer terminal was included in the 500-series. The operate time of the differential function is around 21 ms. The terminal comprises all required hardware and software elements for protection and control of

- big power transformers
- three-phase and single phase auto-transformers
- shunt reactors
- groups with generators and step-up transformers
- special transformers
- tap changers
- etc.
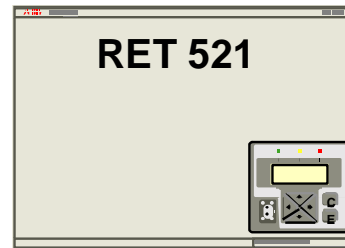
RET 521 Transformer terminal

In 2000, a general differential protection was introduced. The operate time of the differential function is typical 12 ms. The current transformer requirement is < 2 ms to saturation. The application area is:

- Busbars
- Autotransformers
- Generators
- Motors
- Shunt Reactors
- Shunt Capacitors

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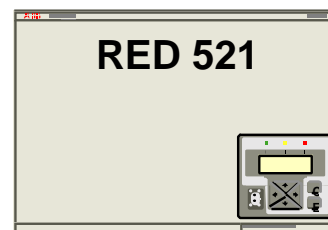
RED 521 General differential protection
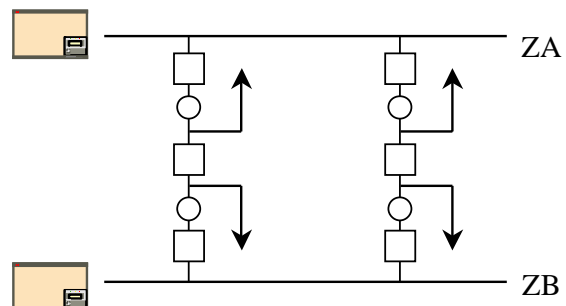
Application of RED 521 1½ Breaker Stations with up to 6 diameters

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## 7. THE INTELLIGENT SUBSTATION POSSIBILITIES AND BENEFIT

The described terminals can be used as stand alone units, with or without the use of serial communication or computers. The full benefits of the new technology will however be obtained in the fully automated substation

Depending on requirements and customer preference the architecture can be designed from a totally distributed concept with one terminal per bay with integrated protection and control, to a sectionalised or centralised concept where one terminal for control functions is connected to several bays. In all alternatives the protection, monitoring and the database is always distributed in each terminal. This means that almost all protection, monitoring and control functions can be distributed to the line and breaker terminals.

The information transfer within the substation is structured on three levels. The station bus is a Local Operative Network (LON), with a speed of 1,25 Mega bits/s, which transfers the information between the object terminals. There is no specific master node, or central bus master. All nodes can communicate directly with each other, over an optical star coupler, which of course increases the fault tolerance. The Gateway for the remote control is connected to the LON bus and converts the required information to a remote protocol, for example IEC 870-101

The Spa bus or IEC 870-103 is used for monitoring information.

Automated substation
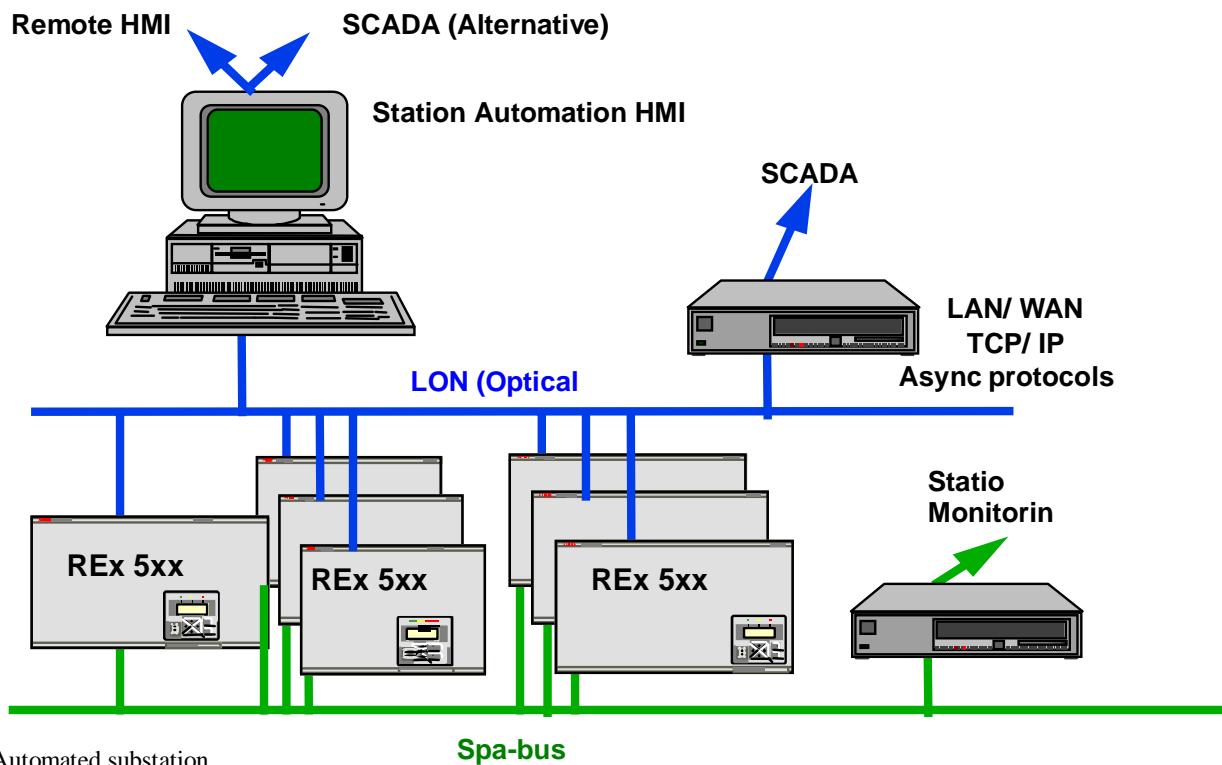
8 SUMMARY

It is impossible to describe the vast range of protection equipment that ABB has developed during 100 years.

However, one has to be impressed with the innovative and creative engineers, which has developed, designed and manufactured relay protection during the electromechanical, static and microprocessor era.

To sound historic
Never has so many had so few to thank for, that electric power have been safely delivered for over 100 years.