**UNIVERSITY OF VAASA**

**FACULTY OF TECHNOLOGY**

**ELECTRICAL ENGINEERING**

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# INTERFACING LOW VOLTAGE DEVICES TO DISTRIBUTION AUTOMATION

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# 1. INTRODUCTION

There are many reasons for the development of traditional networks and Smart Grid evolution. Electricity is the single largest and fastest rising contributor to $CO_2$ emissions. EU is legally committed to reduce greenhouse gas emissions by 20 % by the year 2020 with reference to the 1990 level of emissions and to increase the use of renewable resouces to 20% of energy consumption. More demanding requirements for electricity efficiency are clearly needed in power generation and distribution. This also leads to reconsider the level of power quality, mainly meaning supply reliability and voltage quality. These are setting growing demand for a new generation of distribution network.

Traditional grid includes centralized power generation, and at distribution level one-directional power flow. Next generation grid includes centralized and distributed power generation produced substantially by renewable energy sources. This integrates distributed resources (i.e. generation, loads, storages and electricity vehicles) into energy markets and power systems. One solution, called Smart Grids, can be characterized by controllable multi-directional power flow including local power generation, which serves both supplier and consumer based on real time data, see Figure 1. (Kronman et al. 2009).

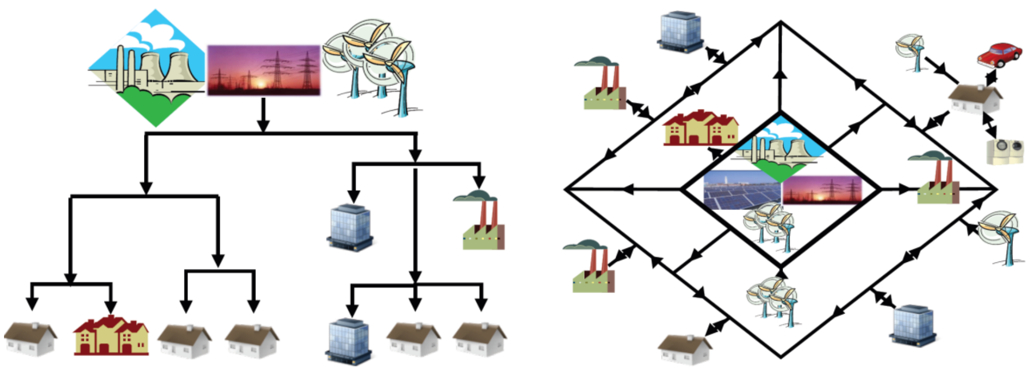

**Figure 1.** Traditional grid and future grid. (Kronman, D. 2010).

The future electric system must be designed to meet requirements of capacity, reliability, energy efficiency and sustainability. These requirements can only be achieved with combination of sensor, communication, information and control technologies in the whole grid i.e. from the production through delivery to utilization. From these arises following Smart Grid main issues – the use of information- and communication technologies (ICT), automation and Advanced Metering Infrastructure (AMI). Automation is needed to guarantee reliable and undisturbed delivery of power, because margins for operation – safety and control – will decrease. AMI is needed for connection Distributed Generation (DG) to distribution network i.e. island operations, management, load control, DSM (Demand Side Management) and active network developing.

Increasing intelligence in grids causes big changes specifically to low voltage distribution, where automation has been modest, even none so far. DG sets pressure to reconsider the automation level of low voltage distribution. This evolution and these requirements will be achieved by smart communication technologies dedicated to power distribution.

Since electrical devices, equipment and control of electric power increases in distribution, it is a worthwhile benefit to identify the range of equipment, applicable standards and their qualification requirements. This study is a part of Cleen Ltd. Research program SGEM (Smart Grids and Energy Market) where it belongs to work package WP4.1 Next Generation ICT-solutions for network management in task 4.1.4 Tools and methods for telecommunication.

This seminar work analyses the state of art of communication interfaces of low voltage devices used today, which is the first phase to determine the right level of automation and communication technologies needed in low voltage distribution in Smart Grids. First the low voltage distribution network and devices are described in general and related standards are introduced. Then devices are studied from safety and operational point of view.

# 2. LOW VOLTAGE DISTRIBUTION IN FINLAND

The electric power network can be separated in Finland to transmission (110 – 400 kV), areal (110 kV) and distribution networks. From transmission grid continues areal networks, which transfer power regionally. Distribution networks can connect straight to the main grid or across areal networks. The difference between areal and distribution networks is based on voltage level; areal networks operate at 110 kV and distribution networks at 20, 10, 1 or 0.4 kV. The other way to divide the electric power network is based on the level of voltage; high voltage 110 – 400 kV, medium voltage 1 – 70 kV and low voltage under 1 kV. (Energiateollisuus 2010).

Generators, substations (110/20 or 110/10 kV) and secondary substations (20/0.4 or 20/1/0.4 kV) are connected to electric power networks. Generators produce energy to power network. Substations are nodal points, where lines of different voltage levels are connected – high to medium voltage. At secondary substations the voltage level is transformed from medium to low voltage suitable to end-user. The majority of secondary substations are pole mounted (85%) and the rest are compact secondary substations or indoor type substations. (Energiateollisuus 2010).

In urban areas compact secondary substations are mostly used and in rural areas pole mounted types. The current trend is to construct weatherproof networks, which means cabled networks and share of compact secondary substations is increasing also in rural areas.

The network in rural area is a radial type, because there are very few end users connected to secondary substation. In urban areas there can be even hundreds of end-users and therefore backup power supplies are arranged by connecting secondary substation together. These form an open ring distribution system, see Figure 2. (Löf, N. 2009).

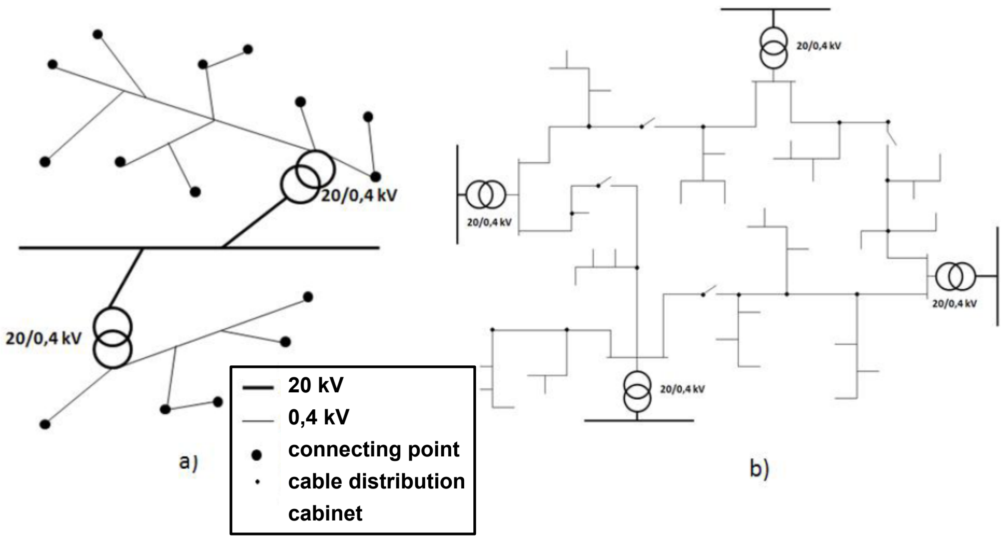


**Figure 2.** Low voltage distribution structure in Finland a) rural areas b) urban areas.

Though low voltage distribution networks in urban areas are ring type, they are operated in radial in order to simplify the protection of the networks. Radial usage is in normal situation where each substation operates independently. The connecting points can be arranged in secondary substation or in a cable distribution cabinet. (Löf, N. 2009).

# 3. STANDARDS FOR LOW VOLTAGE EQUIPMENT AND DEVICES

Standards are needed for common pactices and usage, and they contribute authorities, economy and consumers. Standardization increases compatibility and safety of devices and equipment, protects consumers and environment and supports national and international economy and industry. (Suomen Standarsoimisliitto SFS Oy).

The widest international standardization organization is International Organization for Standardization (ISO). International Electrotechnical Commission (IEC) is responsible in electrical engineering and Telecommunication Union (ITU) in telecommunication standardization. International In Europe alongside with ISO, IEC and ITU there are European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC) in electrical engineering and European Telecommunications Standards Institute (ETSI) in telecommunications. In Finland ISO and CEN are represented by SFS, IEC and CENELEC by SESKO, ITU and ETSI by Viestintävirasto. (Suomen Standarsoimisliitto SFS Oy).

In North America American National Standards Institute (ANSI), Underwriters Laboratories (UL) and CSA International are standardization organizations in electrical engineering. Typically several approvals based on different standards are required for products for international business. The two most recognized standards in the world that influence the design of low voltage switchgear and control gear are issued by the IEC and UL.

Each device has a specific basic function to serve, whereby standards are written for each type of equipment. Dangerous situations are eliminated by different protection methods like earthing, over current and short-circuit protections. Standards for devices for circuit interruption prescribe product characteristics so that it will interrupt current safely, without a hazard of fire or personnel. In normal network operations different types of switching devices are used, and standards prescribe product characteristics so that sufficient operating lifetime is designed without sacrificing safety.

International standard IEC 60947-1, Low- voltage switchgear and control gear, divides low voltage switchgear and control gear to product standards IEC 60947-2...-7 (IEC 60947-1). Primary standards for low voltage fuse are IEC 60269-1…-4 and UL 248. Primary IEC standards in low voltage equipment are IEC 60947 (Low voltage switchgear and control gear) and IEC 60439-1 (Type-tested and partially type tested assemblies), Primary UL standards are UL 98, UL 977, UL 508, UL 1008, UL 489, UL 1066, UL 891 and UL 1558. In the Table 1 are standards applicable to low voltage electrical equipment presented.

**Table 1.** Standards applicable to low voltage electrical equipment. (ASCO 2010).

| **Product** | **IEC** | **UL** |
|---|---|---|
| Circuit Breakers | 60947-1,-2 | 489, 1066 |
| Switches, Disconnectors, Fuse combination units | 60947-1,-3 | 98, 977 |
| Contactors, Magnetic Starters | 60947-1,-4 | 508 |
| Automatic Transfer Switches | 60947-1,-3,-6 | 1008 |
| Switchgear and controlgear assemblies | 60439-1 | 891, 1558 |

Safety and protection of low voltage distribution networks are regulated in Finland in Sähköturvallisuuslaki 410/1996. Criteria’s for power quality in low voltage distribution are regulated in SFS-EN 50160 and in Sener publication: ”Jakeluverkon sähkön laadun arviointi”. These are setting requirements for measuring devices, which are either separated or integrated in the primary device.

Some key standards for telecommunication in distribution networks are:

- IEC60870-5: A protocol standard for electric power systems
- IEC61850: The new international standard for communication in substations.
- Modbus: A de facto protocol standard for messaging structure, used to establish master-slave/client-server communication between intelligent devices.

Content of these standards is not further considered in this seminar work.

# 4. DEVICES IN LOW VOLTAGE DISTRIBUTION

Sustainability is the leading value of developing distribution networks. The power distribution process and the power system equipment need to be carefully planned and implemented in order to comply with the future demand.

Information exchange and data mining will be more complex in Smart Grids and Micro Grids, because of the utilization of distributed energy resources and the efficient use of energy. Open communication is in the key role connecting different devices, systems, maintenance staffs and business partners together in real time. Transparent data exchange makes it possible to better exploit functions for safety-, operation-, asset- and business management in power distribution. The picture below describes the modeling type, which gives data access for each aforesaid management sector. (Antila, E. & Wiklund, G. 2009).

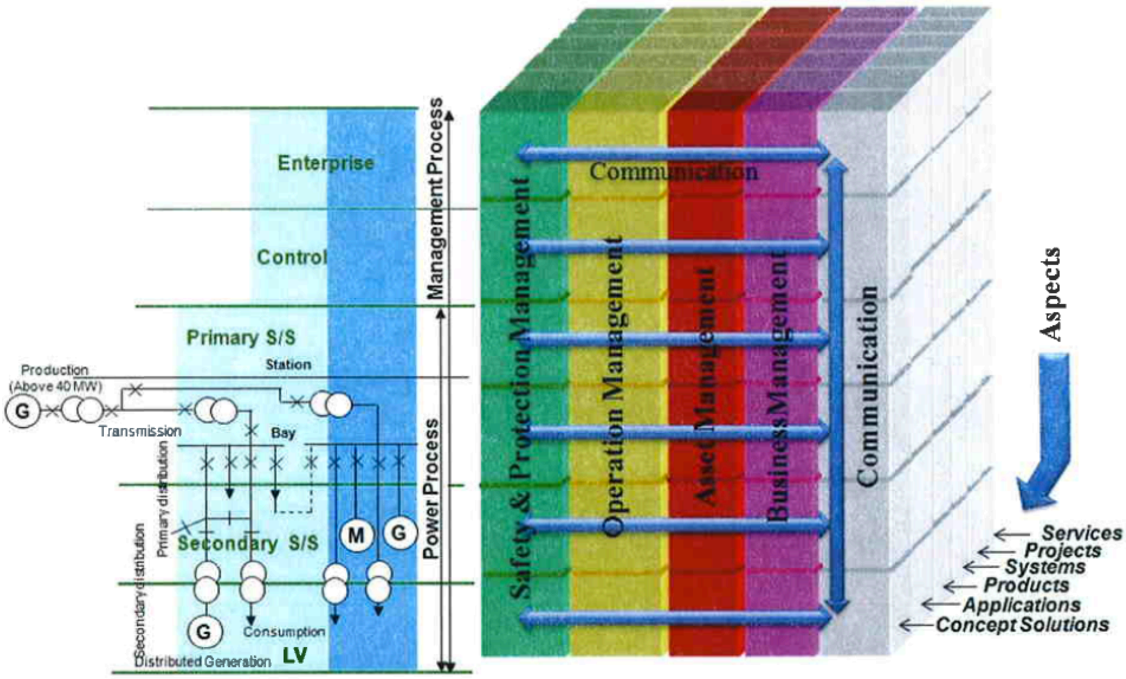


**Figure 3.** "The three dimensional" model for data access. (Antila, E. & Wiklund, G. 2009).

The communication between devices and systems according to the foregoing model gives an opportunity to elaborate data exchange, and to process the needs to each management sectors. Communication interfaces are investigated in order to find the communication medias and protocols used in low voltage devices currently. This gives an opportunity to develop further the data access in low voltage distribution.

The basic focus to manage the low voltage electrical distribution networks is on protection, switching, control, isolation and economy. Protection has the value when the objective is to limit a faulty part of the network to the affected section only by interrupting the supply of current. Switching and control are on focus under normal operation of the network, the ability to supply or interrupt the supply of electrical current to a section of a network or an individual load to command. Isolation is condition of ensuring that part of a network or a load is positively and securely disconnected from the supply of electricity. Demands of economy lead to the cost effective operation of a distribution network. All these aspects are considerable when choosing devices to low voltage distribution networks. As there are increasing demands for even safer equipment, closer protection and more and more automation and remote control, the options are widening. (Mennell, T.W 1997).

The Figure 4 is showing as an example locations and applications for safety and control devices used in low voltage distribution. These devices are mainly used in secondary substation, cable distribution cabinets and commercial and industrial main distribution boards. For the protection it is shown both alternatives in parallel – breaker- and fuse-gear-based system.

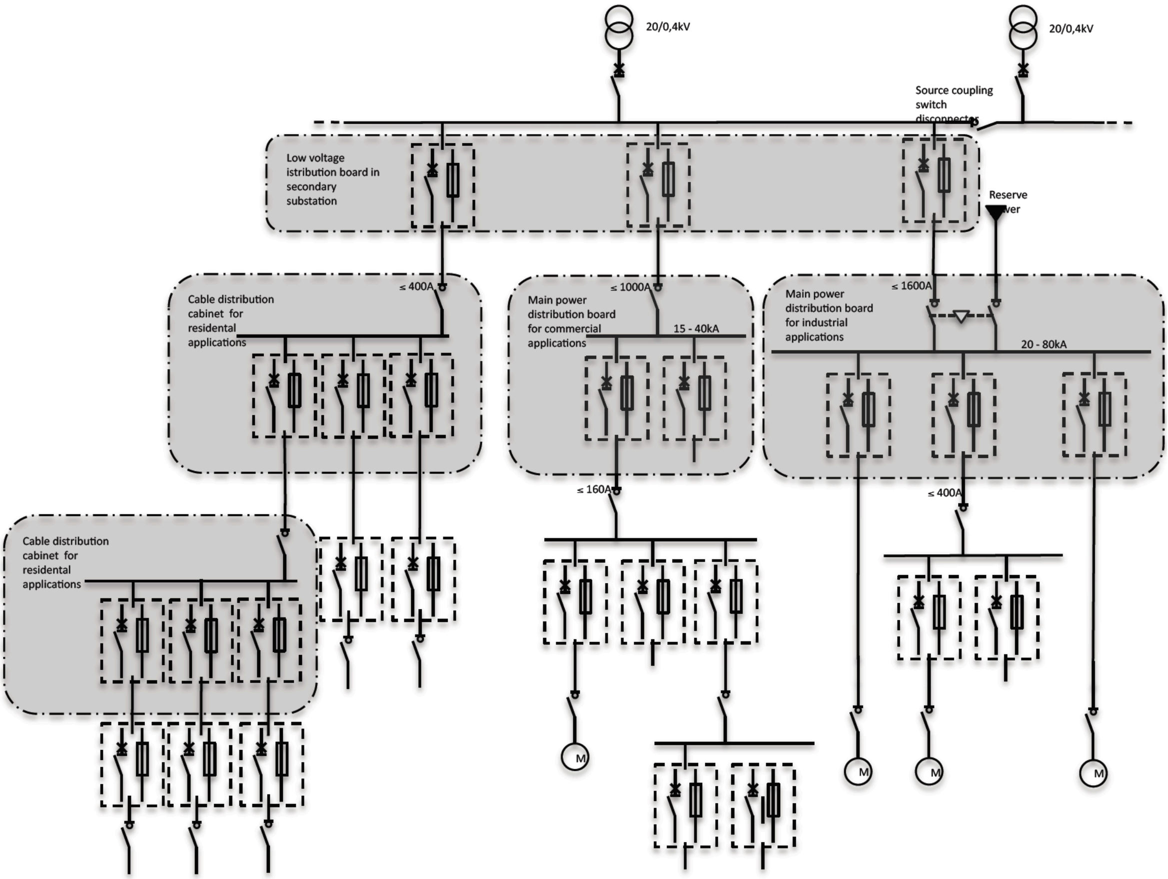


**Figure 4.** Applications and locations of protection and control devices in low voltage distribution.

## 4.1. Safety and protection devices

Basic requirement for safety devices is protection against short circuit and over current. Additional protection function can be for example protection against earth fault or transients. The protection is implemented by either fuse-based or by circuit breaker-based technology. In Finland the fuse-based system is commonly used in low voltage distribution. In the fuse-based system the excess current is overheating and melting a short fusible length of conductor, the fuse link, causing switching and isolation of the line. In the circuit breaker-based system there is a relay for the detection of an abnormal current, which initiates the mechanical separation of contacts. Switching and isolation is achieved by mechanical operation of the same contacts.

### 4.1.1. Fuses

Fuses are simple and affordable protection devices against short circuit, some types can protect over load too. A fuse consists of a fuse link mounted on a fuse base. IEC standards refer to a "fuse" as the assembly of a fuse link and fuse holder. In North American standards the "fuse" is the replaceable portion of the assembly, and a "fuse link" would be a bare metal element for installation in a fuse. The type of fuse holders can vary for example DIN, BS, NFC and UL depending of markets – DIN -type is used in Finland. The drawing symbol of a fuse is in Appendix 1, Table 2.

DIN-type fuses used in low voltage distribution in Finland have the rated voltage, $U_e$, up to 500 V with rated current $I_e$ from 2 to 1250 A. Short circuit breaking capacity $I_c$ can be up to 120 kA and over. The fuse links limit the unlimited prospective short circuit current ($I_p$) to cut-off current ($I_c$) (see Figure 5 and 6) quickly and therefore the energy let through ($I^2t$) of a fuse is low as shown in Figure 7. These fuses operate in less than one cycle of the AC power frequency, which other protective devices cannot achieve. This current limiting characteristics protects the equipment and cables with optimal dimensioning.

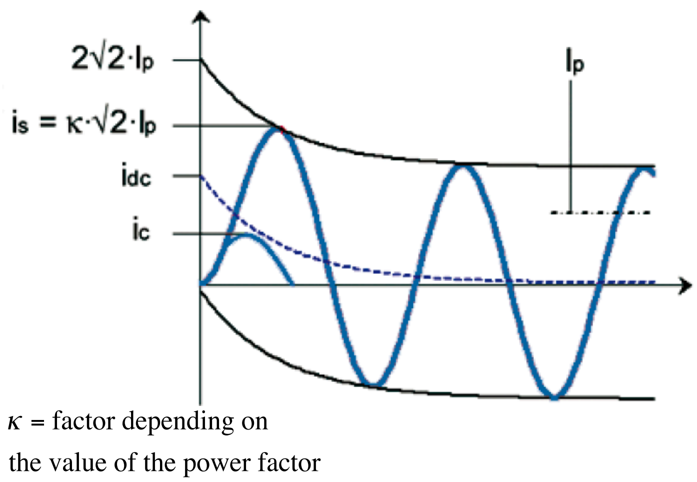


**Figure 5.** Limited prospective short circuit current. (ABB 2010g).

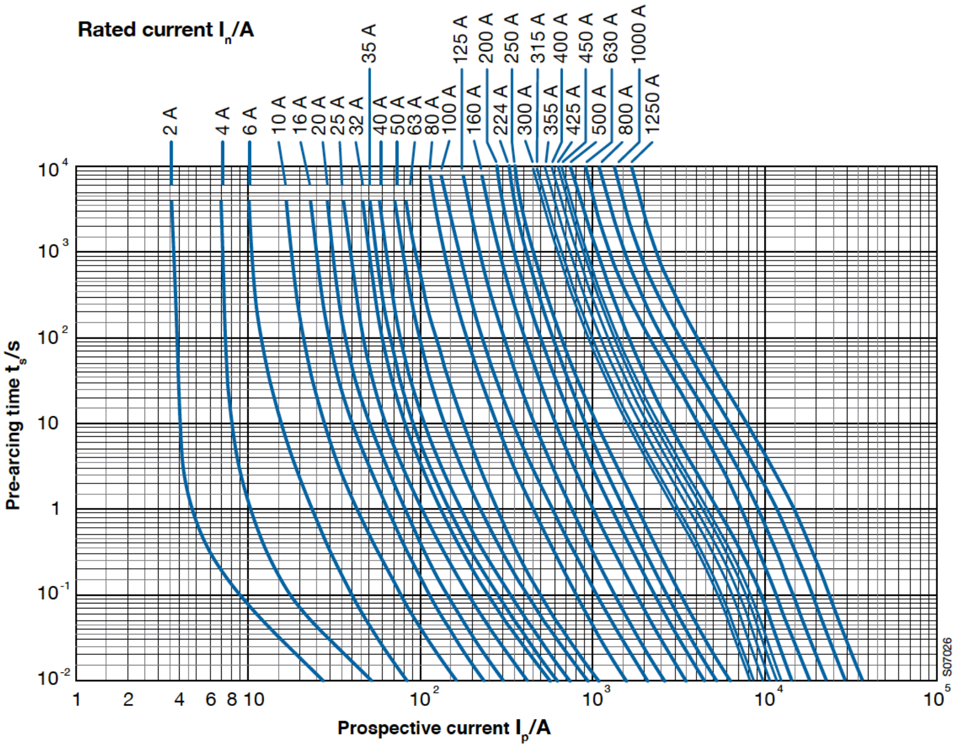


**Figure 6.** Time-current characteristics, 500V, gG fuse links OFAF_H_. (ABB 2010g).

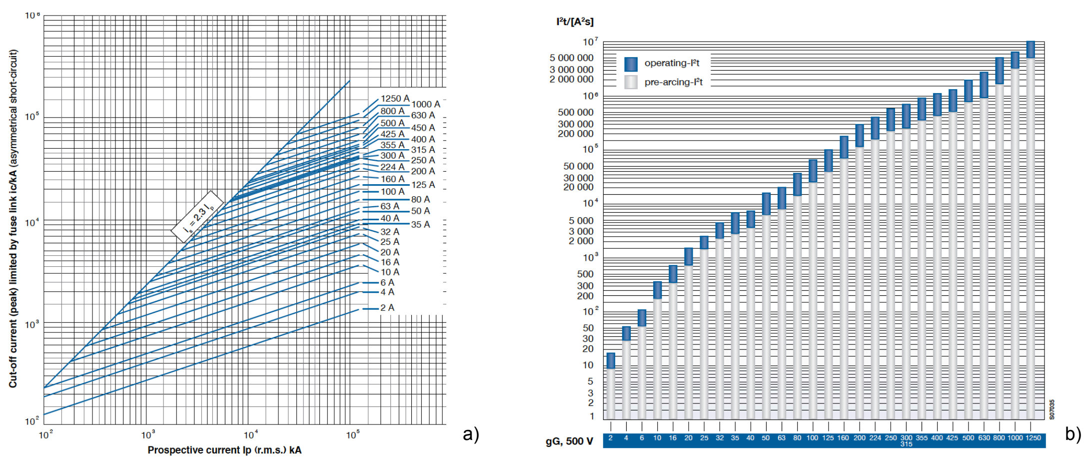


**Figure 7.** Current limitation a) and I2t characteristics b) for 500V, gG fuse links OFAF_H_. (ABB 2010g).

The main manufactures of fuses are Ferraz and Bussmann. For monitoring and control of fuses there is available electronic fuse monitoring devices, which indicates the status of the fuse with led lamps, and the monitor gives a notice of a blown fuse with auxiliary contact information. A mechanical fuse blown indicator with auxiliary contacts is available for striker type fuses.

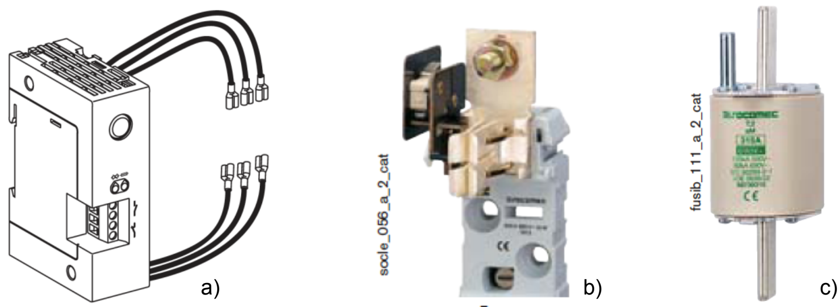


**Figure 8.** An electronic fuse monitor a), a fuse base with a striker b) and a striker type (DIN) fuse link c).

4.1.2. Fuse combination units

A fuse-combination unit is a combination of a mechanical switching device and one or more fuses in a composite unit. The fuse combination units can be divided to switch fuses and fuse switches. In principal switch fuses consists of a load break switch and fuses per phase, which can be vertically or in parallel mounted. The main difference between a switch fuse and a fuse switch is the switching event – when operating a switch fuse, contacts of the switch unit are moving (independent operation) and when operating a fuse switch, fuses are the moving contacts (semi-independent operation). The difference can be recognized in drawing symbols, see Appendix 1, Table 1. (IEC 60947-3 2008).

Typically switch fuse ranges covers 160 – 630 A, but there is available switch fuses up to 1250 A. Fuse holders are DIN, BS, NFC and UL types. Performances required of fuse-combination units are the same as switches according to IEC 60947-3 (see chapter 4.2.1.).

ABB, Efen, Schneider Electric, Jean Müller, Siemens and Socomec are the biggest manufacturers of switch fuses and fuse switches. ABB and Socomec cover one third of the market. (ABB 2010e).

Switch fuses can generally be equipped with auxiliary contacts for position indication and most manufacturers have a blown fuse indication as an accessory. Electronic fuse monitors are available for the fuse status indication. ABB has a motorized switch fuse range OSM from 23 to 1250 A (ABB 2010a). Socomec has a series Fusomat from 250 to 1250 A, which can be remotely tripped (Socomec 2008a). Change over switch fuses are available from Socomec from 20 to 400 A, which are manual operated (Socomec 2008b). ABB offers conversion kits for 6- and 8-pole, change over and by-pass switches (ABB 2010f). More details about changeover and bypass switches will be presented in chapter 4.2.1.

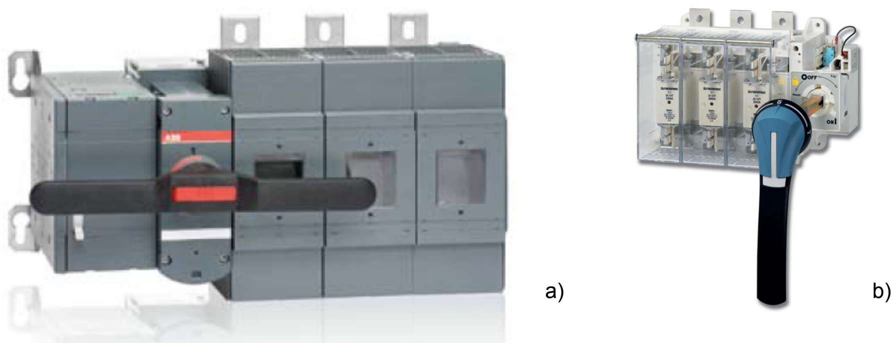


**Figure 9.** A 1250 A motorized switch fuse from ABB a) and a 250 A switch fuse with trip operation from Socomec b).

**Figure 10.** A manual operated changeover switch fuse from Socomec.

Vertical type fuse switches are from 160  to 1600 A and horizontal types from 160 to 2500 A. Generally auxiliary contacts are available for position indication. Blown fuse indication devices and electronic fuse monitoring and indication devices are available. Vertical types have housing for ammeter. (ABB 2000; 2006; 2008; Schneider Electric 2006; 2010b).

Efen has $E^3$-NH-series vertical design switch fuses from 160 to 630 A. The series can be equipped with auxiliary contacts and with an integrated multi-measurement device (Efen EM). The measurement unit has current measurements, power metering, harmonic wave analysis, remote control and alarm relays. The communication protocol is Modbus/Jbus. Additional measurement options can be realized with an ammeter, which is adjusted onto the bracket. An electronic fuse monitoring is available from Efen and notification of a blown fuse is sent via SMS or PC. (Efen 2010).

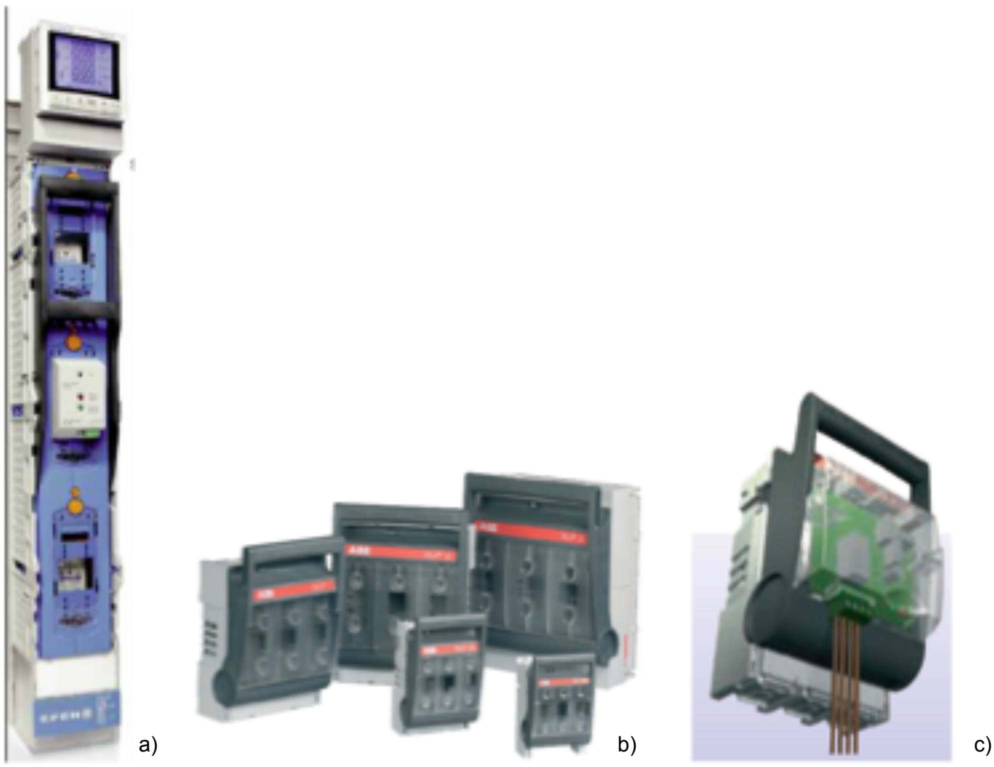


**Figure 11.** An $E^3$-NH-series vertical type switch fuse from Efen with a fuse monitor a), a horizontal type fuse range b) and a horisontal type switch fuse equipped with a fuse monitor c).

### 4.1.3. Circuit breakers

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit against overload or short circuit. Its basic function sense when an over current occurs, measure the amount of over current and act by tripping the circuit breaker in a time to prevent damage to itself and the associated load cables. (Siemens 2010a). Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset either manually or automatically to resume normal operation.

Circuit breakers are constructed in a frame with contacts and arc chute assembly, an operating mechanism and a trip unit.

The trip unit is the “brain” of the circuit breaker. It consists of components that will automatically trip the circuit breaker when it senses an overload or short circuit. The operating mechanism is held in the “ON” position by the trip mechanism. When a trip is activated, the trip mechanism releases the operating mechanism, which opens the contacts. (Siemens 2010a).

The trip unit can be a manual – circuit breaker can be manually tripped by pressing the “Push-to-Trip” button on the face of the circuit breaker (see figure 12a). This allows the trip mechanism to “unlock” circuit breaker releasing the operating mechanism, which opens the contacts. (Siemens 2010a).

In a thermal-magnetic trip unit, the overload is sensed with a bimetallic strip. When over current flows through the circuit breaker’s current path, heat build up causes the bimetallic strip to bend and opens the trip mechanism (see figure 12b). Short circuit causes magnetic fields forcing contacts apart (see figure 13). The operation time depends on the magnitude of the current – the greater the fault current, the greater is the magnetic field and shorter the time to interrupt the current. (Siemens 2010a).

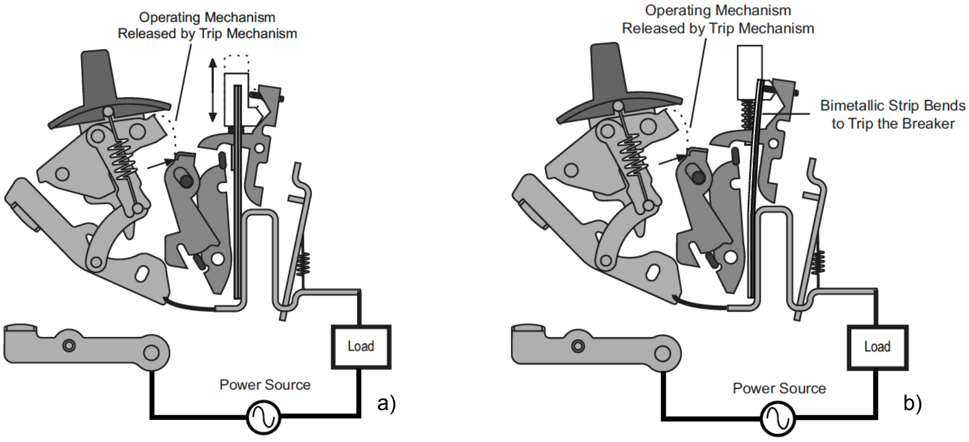


**Figure 12.** A manual trip a) and an overload trip b). (Siemens 2010a).

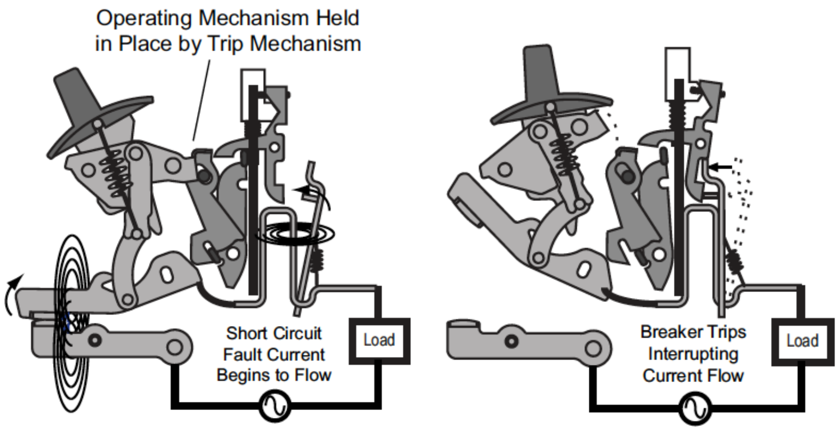


**Figure 13.** A short circuit trip. (Siemens 2010a).

A solid-state trip unit (see Figure 14) allows a solid-state circuit breaker to have programmable features and improved accuracy and repeatability. Current sensors connected to the trip unit monitor the load current. When current exceeds a preset value for the selected time, the trip unit triggers a magnetic latch. The magnetic latch opens the breaker's contacts, disconnecting the protected circuit from the power source. The brain of a solid-state trip unit is a microprocessor. Adjustments on the trip unit set numerical values that the microprocessor uses in performing protective functions. (Siemens 2010a).

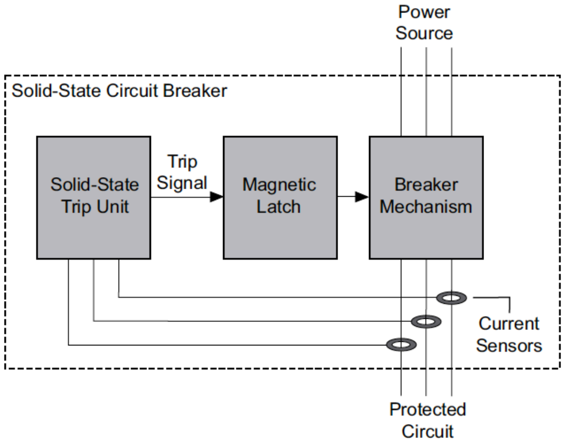


**Figure 14.** A solid-state trip unit. (Siemens 2010a).

Electronic trip units are developed with several functions of protection, measurement, signaling, data storage and control.

The circuit-breaker main characteristics according to IEC 60947-2 are making, carrying and breaking currents under normal circuit conditions, and also making and carrying abnormal circuit conditions such as those of short circuit (IEC 60947-2 2006:12). Main characteristics are performance, rated current $I_u$, rated short circuit making capacity $I_{cm}$, ultimate breaking capacity under short circuit $I_{cu}$, service breaking capacity under short circuit $I_{cs}$ and rated short time withstand current $I_{cw}$ (1s).

Mostly used breakers in low voltage distribution are Air Circuit Breakers (ACB) and Molded Case Circuit Breakers (MCCB). An air circuit breaker contacts open and close in air at atmospheric pressure. A molded case circuit breaker has a supporting housing of molded insulating material forming an integral part of the circuit breaker. (IEC60947-2 2006:13).

The current limiting capacity of a circuit breaker is provided by two different ways like in fuses. The Figure 15 shows current limiting capacities of an ACB and a MCCB, the peak value in relation to the uninterrupted symmetrical short circuit current. The Figure 16 shows the energy let through ($I^2t$) of an ACB and a MCCB.

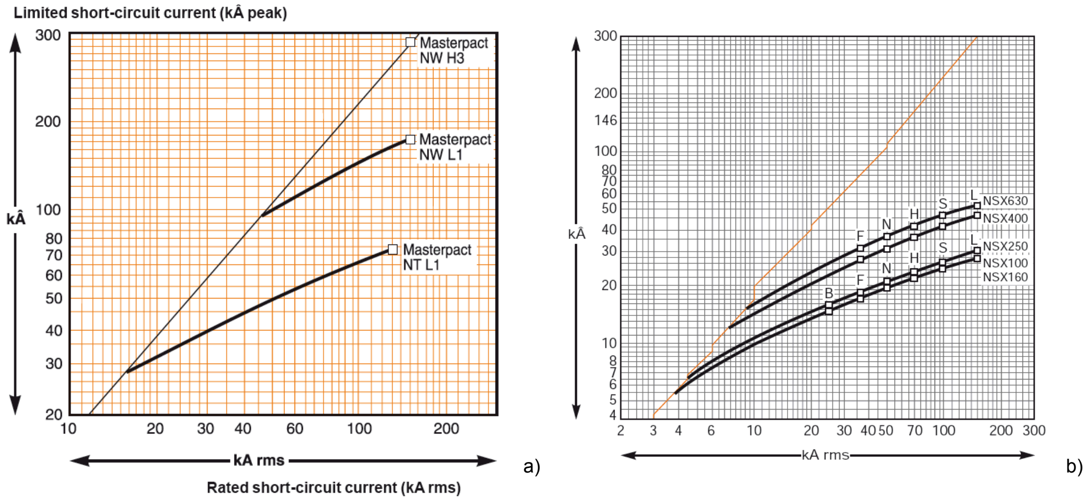


**Figure 15.** Limited short circuit current of ACB a) MCCB b) of Schneider Electric circuit breakers. (Schneider Electric 2009a; 2009b).

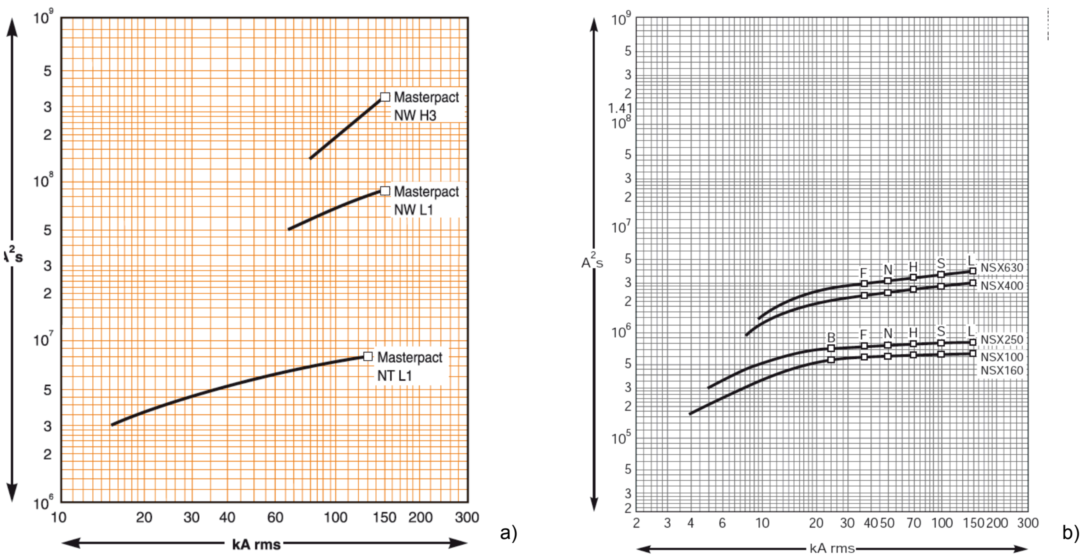


**Figure 16.** Limited energy (let through) of ACB a) MCCB b) of Schneider Electric circuit breakers. (Schneider Electric 2009a; 2009b).

ACB's are available from 630 to 6000 A. Main manufacturers are ABB, Schneider Electric and Siemens having some over 50% of the market. (ABB 2010e). MCCB's are available from 15 to 1600 A, and Eaton has series C up to 2500 A. Main manufacturers are ABB, Schneider Electric, Siemens and Eaton having over 50% of the market. (ABB 2010e). In this content the breakers of previously mentioned manufactures have been studied and compared.

Basic protection functions for ACB and MCCB with trip units are overload, short circuit, instantaneous short circuit, earth fault and neutral protection. ACB have more sophisticated protection functions usually than MCCB. ABB Tmax series (MCCB) has electronic trip units with advanced protection functios, see Table 2. (ABB 2010b; 2010c; Siemens 2004; 2005; Schneider Electric 2009a; 2009b; 2010b).

**Table 2.** ACB and MCCB protection functions.

| Common protection functions | | ACB | MCCB |
|---|---|---|---|
| Overload | L | X | X |
| Short circuit with delay (selective short circuit) | S | X | X |
| Instantaneous short circuit | I | X | X |
| Earth fault | G | X | X |
| Neutral overload | N | X | X |
| Advanced protection functions | | ACB | MCCB |
| Directional short-circuit (with adjustable delay) | D | X | |
| Earth fault (with adjustable delay) | | X | X (* |
| Phase unbalance | U | X | X (* |
| Phase sequence | | X | |
| Over temperature of trip/thermal memory | OT | X | X (* |
| Load control | K | X | X (* |
| Reverse power | RP | X | X (* |
| Under-/over-/residual voltage | UV/OV/RV | X | |
| Under-/overfrequency | UF/OF | X | X (* |
| Residual current (vaihtoehto G:lle)/Earth leakage/Vikavirtasuoja | RC | X | X |
| Zone selectivity | ZS | X | X |
| X = Commonly used protection functions in breakers by main manufacturers | | | |
| X (* = Protection unit for ABB Tmax series | | | |

The Figure 17 is showing the typical curves of ACB and MCCB protections against overload (L), short-circuit with delay (S) and instantaneous short-circuit (I). Normally thresholds are for over load protection 0,4 – 1 x $I_n$, for selective short-circuit protection 0,6 – 10 x $I_n$ and for instantaneous short-circuit 1,5 – 15 x $I_n$.

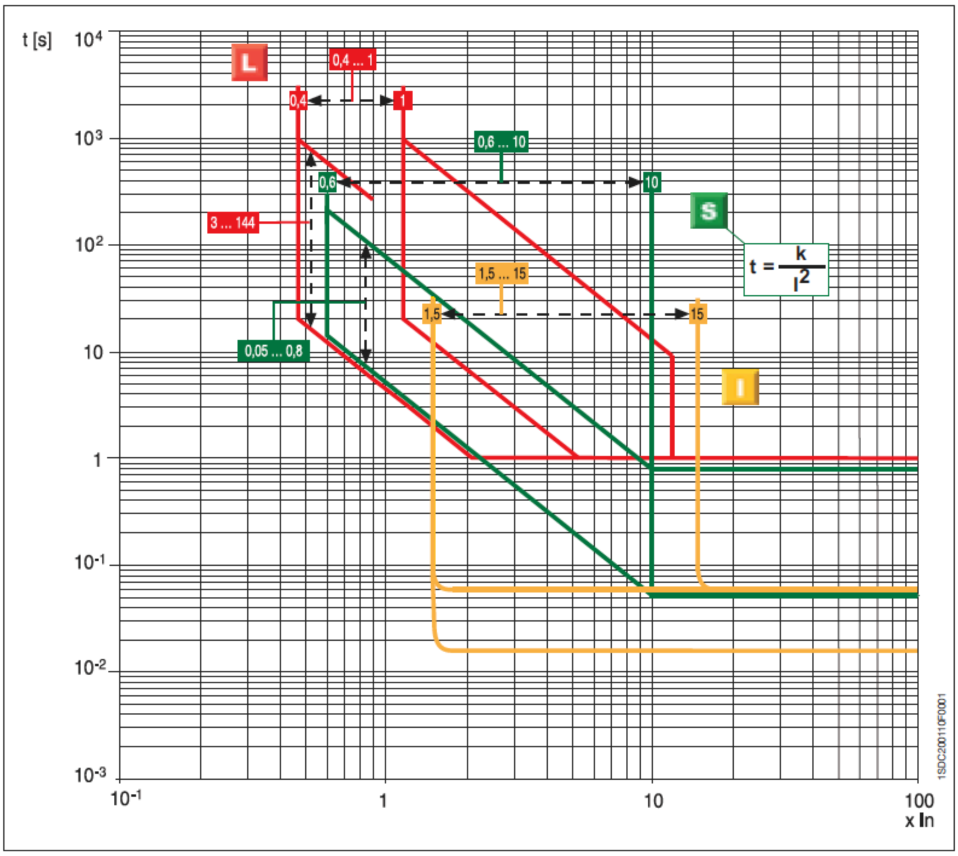


**Figure 17.** Trip curves of protection functions (L, S and I) of a circuit breaker. (ABB 2010b).

Basic measurements for ACB and MCCB are currents (three phases, neutral and earth fault). Advanced measurements are voltage (phase to phase, phase to neutral, unbalance, residual), power (active, reactive, apparent power factor) and frequency as shown in Table 3. Schneider Electric has in addition to previous measurements quality (Total Harmonic Distortion – THD, fundamental wave forms for currents and voltages, current and voltage harmonics) and demand values (currents and power). See Table 3 (ABB 2010b; 2010c; Siemens 2004; 2005; Schneider Electric 2009a; 2009b; 2010b).

**Table 1.** ACB and MCCB measurement functions.

| Common measurements | ACB | MCCB |
|---|---|---|
| Currents | X | X |
| Advanced measurements | ACB | MCCB |
| Voltages | X | X |
| Power | X | X |
| Energy | X | X |
| Frequency | X | X |
| Power quality indicators | X | X (*2 |
| Demand values | X (*1 | X (*2 |
| X = Common measurements in breakers by main manufacturers | | |
| X (*1 = Protection unit for Schneider Masterpact NT/NW series | | |
| X (*2 = Protection unit for Schneider Electric Compact NSX series | | |

Circuit breakers, where only basic protection functions can achieved, have a thermo-magnetic protection relays. Indications of protection event are maintained with LED lamps of protection relay. Parameterization is usually made with DIP-switches. For extending the information of CB using PC, wireless communication Bluetooth is available. An electric signaling module, which changes digital signals to analog via auxiliary contacts, allows the remote signaling of alarms and trips. The module might include configurable contacts for any possible event or alarm. Additionally the signaling contacts can be configured freely for example protection settings; protection type, time and trip.

Circuit breakers with advanced protection functions (electronic trip units) and measurements can be connected to communication bus. The connection is made between an electronic trip unit, a measurement unit (if not included in trip unit) and a communication module. The communication module is mainly for Modbus communication. The protocol is mainly Modbus RTU, physical layer is RS-485 and maximum baud rate is 19200 bps. A module for Profibus, DeviceNet or AS-I connections is available to ABB Emax- and Tmax- series with a Fieldbus Plug (ABB 2010b; 2010c).

The communication network is used for remote control of circuit breakers and to read all information available in the protection trip unit. Data available:

- Measurements: all measured values: currents, voltages, power, energy, frequency and quality
- Alarms and warnings: different protection functions performed per protection type (short-circuit, overload, etc.)
- Maintenance: number of operations (manually and per trips), contact wear and data for last trip
- Operating: mode (local, remote), status of CB (open/close/reset), setting values, time synchronization

Electrical accessories are needed to provide the desired operation and functionality of a circuit breaker. For example different kinds of trip coils and spring charging motors are needed for remote control, auxiliary contacts are used for remote signaling the state of the breaker and its contacts. For remote signaling or actuation of automatic functions it is needed for example under voltage release, over current release and auxiliary contacts. Other devices can be auxiliary supply, signaling module, transformer and ATS-unit.

A user interface panel is generally available on the front side of switchboard, where measurements, alarms/events of the trip unit are shown. The panel is typically connected to trip unit via serial line. For circuit breaker testing and configuration locally there is configuration test units, which can test, program and read parameters for protection units.

Automatic Transfer Switch (ATS) solutions are available for ACB and for MCCB. ATS consist of an automatic control unit and two circuit breakers equipped with interlocking device. ACB based ATS solution are available from ABB, Schneider Electric and Siemens (ABB 2009, Schneider Electric 2009b, Siemens 2010b). MCCB based ATS solution are available from ABB, Schneider Electric and Siemens (ABB 2009, Schneider Electric 2010b, Siemens 2010b). Communications are executed with

Modbus. Eaton has a series of enclosed breaker-based transfer switches from 30 to 1000 A with communication (Eaton 2010).

Circuit breakers can be used as a switch-disconnector, and in this application they are not provided with a protection unit. Into circuit breaker-based switch can be installed the same accessories as in circuit breakers, but without measurement and communication capabilities. (Rönnholm, P. 2010).

## 4.2. Control and operation devices

Switching devices are used for control and operation in distribution network, which means controlling the power flow and isolating or connecting different parts of the network and the devices are designed to make or break the current in one or more electric circuits. Devices that fall under this classification can be circuit breakers, load-break switches or load break switch-disconnectors.

### 4.2.1. Switches, disconnectors, switch-disconnectors

Performance required of switches and switch disconnectors according to IEC60947-3 are making, carrying and breaking capacity of currents under normal and specified abnormal circuit conditions. The main characteristics are rated operational current $I_e$, rated thermal current in free air $I_{th}$ and enclosed $I_{the}$, rated making capacity, rated breaking capacity, rated short-time withstand current $I_{cw}$, rated short time making capacity $I_{cm}$. Performances required from a disconnector are rated operational current ($I_e$), rated thermal current in free air ($I_{th}$) and enclosed ($I_{the}$). Load break switches have typically a range rated current $I_e$ from 16 to 4000 A.

The definitions for a switch, a disconnector and a switch disconnector according to standard IEC 60947 are:

*A switch (mechanical)*: A mechanical switching device is capable of making, carrying and breaking currents under normal circuit conditions which may include specified operating overload conditions and also carrying for a specified time currents under specified abnormal circuit conditions such as those of short circuit. (IEC60947-3 2007: 22.) A switch may be capable of making, but not breaking, short-circuit currents.

*A disconnector*: A mechanical switching device, which, in the open position, complies with the requirements specified for the isolating function. (IEC 60947-3 2007: 22.) A disconnector is capable of opening and closing a circuit when either a negligible current is broken or made, or when no significant change in the voltage across the terminals of each of the poles of the disconnector occurs. It is also capable of carrying currents under normal circuit conditions and carrying, for a specified time, currents under abnormal conditions such as those of short circuit.

*A switch-disconnector*: A switch, which, in the open position, satisfies the isolating requirements specified for a disconnector. (IEC 60947-3 2007: 22.)

Load break switches are basic on – off (I – O), change over (I – 0 – II or I – I+II – II) or bypass isolation types (I – 0 – II or I – I+II – II), see circuit diagrams in Appendix 1, Table 1 and Table 2.

The market leaders of manufacturers are ABB and Socomec. Change over switch manufacturers are mainly ABB (motor operated), Schneider Electric (manual operated), Siemens, Socomec (motor operated), Eaton and Mitsubishi. Market shares are relatively equally divided with main competitors. (ABB 2010e).

Switches and disconnectors are usually manually operated with handle and position indication is obtained with auxiliary contacts. ABB offers switches, which can be equipped with electrical interlock. Socomec has load break switches with trip functionality. A remote controllable switch requires a motor operator to make switching. A motor operator needs a separate power supply. Control signal can be supplied separately or there can be voltage free contacts.

An automatic transfer switch (ATS) is intended mostly to reserve power supply for example to switching between the main supply and a generator set. Automatic transfer switches can also be used in critical loads and UPS utilizations. Therefore in the market there are many versions making difference between switching time; Open Transition Transfer Switch (OTTS), Closed Transition Transfer Switch (CTTS) and Fast Transition Transfer Switch (FTTS).

Two main manufactures of automatic transfer switches are ABB and Socomec. ABB has range from 160 – 2500 A (ABB 2010d) and Socomec has 125 – 3200 A (Socomec 2008c). Communication plug in modules have Modbus-protocol.

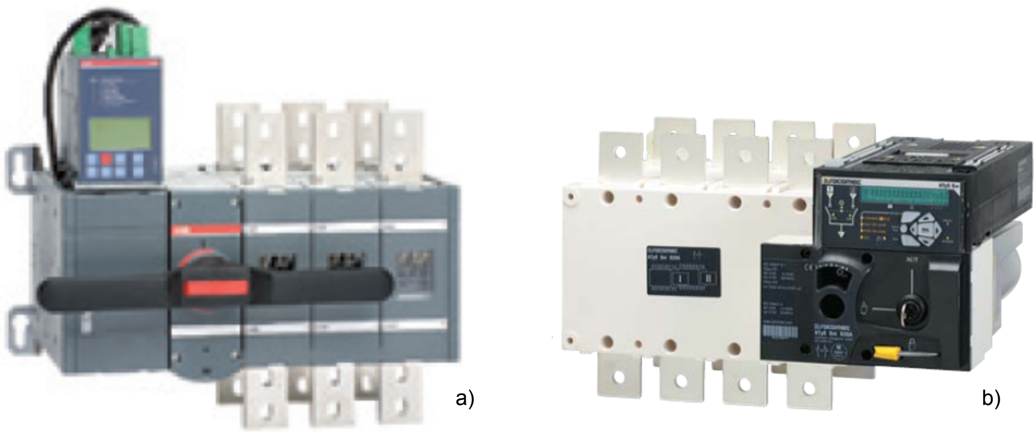


**Figure 18.** Automatic Transfer Switch from a) ABB and b) Socomec.

4.2.2. Contactors

A contactor can be described an electrically controlled switch used for switching a power circuit, similar to relay except with higher amperage ratings. A contactor is controlled by a coil, fed by auxiliary voltage. Unlike a circuit breaker, a contactor is not intended to interrupt a short circuit current. Contactors are rated by rated load current ($I_e$), maximum fault withstand current, duty cycle, voltage ($U_e$), coil voltage and utilization category (or rated powers). (IEC 60947-4).

The definition for a contactor according to standard IEC 60947-3 is:

*A contactor (mechanical)*: A mechanical switching device having only one position of rest, operated otherwise than by hand, capable of making, carrying and breaking currents under normal circuit conditions including operating overload conditions. (IEC 60947-3 2007: 22).

Typically there are several different coils to choose in AC from 12 up to 600 V and in DC from 12 up to 240 V. ABB´s new contactors AF1350/AF1650 are equipped with electronic coil interface at voltage range 100 – 250 V AC and DC. These contactors are as standard equipped with low voltage inputs for control, for example by a PLC. (ABB 2004).

Auxiliary contacts are available for device position indication as well as electrical interlocking devices.

Eaton has a series of enclosed contactor based transfer switches from 40 to 1200 A (Eaton 2010).

## 4.3. Summary

Prepardeness of low voltage devices to communication technology is having increasing role. Currently circuit breakers are the most intelligent devices thinking of next generation of low distribution networks. Wide scope of protection and measurement functionalities with communication makes possible the information and data exchange. Communication technologies used in circuit breakes are developed to meet industrial needs mostly (Modbus).

In switching and fuse-based devices the communication availabilities are mostly arranged via contact information. Motor operators of load break switches and switch fuses makes it possible to remote control of devices. Different solutions of reverse power connecting (ATS) are established with load-break switches, circuit breakers and contactors with different solutions. ATS- devices are most advanced in communication technologies, the communication protcol used in ATS-devices is Modbus.

Fuse based protection is an economical and efficient solution for protecting distribution networks. Current limiting characteristics and operating time in short circuit protection have still the value choosing the protective device. Communication availabilities have to be developed to meet future needs (measurement, status, protection functions, etc.).

# 5. CONCLUSIONS

The study included examination of protection and control devices used in low voltage distribution and their eventual interfaces to distribution automation. The protection devices examined were fuses, ACB and MCCB and control devices dealing with load-break switch-disconnectors. The features of devices were considered of functions for safety-, operation-, asset- and business management in power distribution. The Figure 22 below describes functionalities found from devices in low voltage distribution.

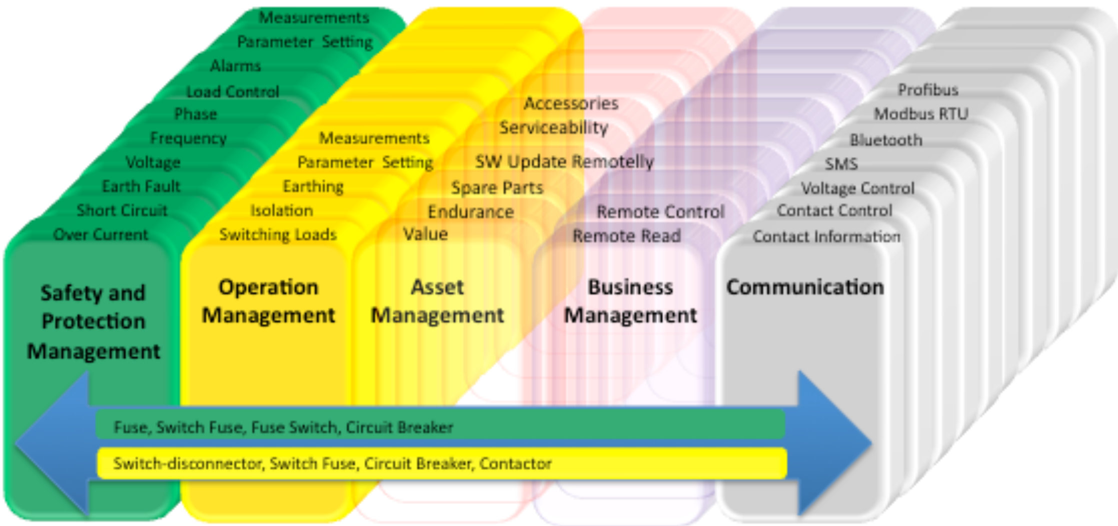


**Figure 19.** Functionalities of devices used in low voltage distribution.

Fuse-based protection compared to breaker-based technology still has a strong position in protection of low voltage distribution beacuse of economy, simplity and short circuit breaking capacity. In Finland the protection in low voltage distribution is executed by fuse-based system. Automation of devices implemented by fuse technology will increase, and because of simplity, economic efficency and high short circuit breaking capacity, this will be a valuable solution for protecting low voltage distribution grids in the future too.

Self-recovering fuses might be a technology which could challenge the increasing importance and share of breaker technologies. This requires that self-recovering fuses will maintain the same short circuit breaking capacity as as current fuse technology. This could eliminate the the manual operation after fault situations.

The most important targets for developing circuit breakers will be current limiting and higher short circuit breaking capacities, because the trend of transformer sizes will increase in the future and there will be more feeders in parallel. Communication of circuit breakers will increase. Communication protocol used today is Modbus. Imbending improvement of communication in air circuit breakers is communication according to IEC 61850 protocol. MCCB measurement features will improve in the nearest future. On the other hand there is home automation systems development, which will show the way to develop communication in MCCB's. Smart Micro Grids will set reqirements for measuring and communication. The requirements, standards and regulations are pending.

More compact solutions of devices are under development to guarantee the safety requirements for example changeover-, bypass- and parallel connections for different applications needed especially for distributed generation. Development of integrated measeurement functionalies is ongoing.

Insulation and impulse voltage widthstand characteristis will be more important when selecting and using devices in distributed generation.

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# APPENDICES

## Appendix 1. Graphical symbols

**Table 1.** Summary of equipment definitions (IEC 60947-3 2008).

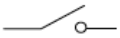
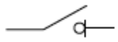
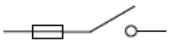
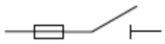
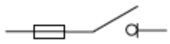
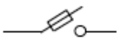
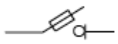
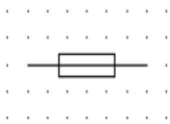
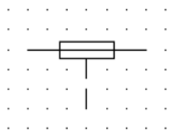
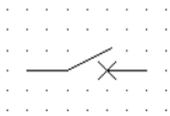
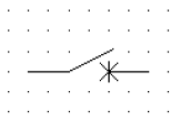
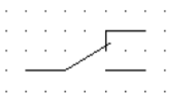
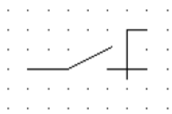
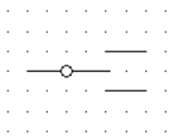
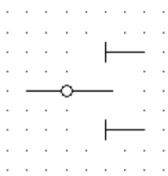
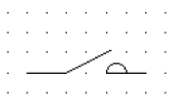
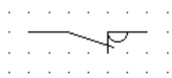
| Functions | | |
|---|---|---|
| **Making and breaking current** | **Isolating** | **Making, breaking and isolating** |
| Switch<br>2.1<br> | Disconnector<br>2.2<br> | Switch-disconnector<br>2.3<br> |
| **Fuse-combination units 2.4** | | |
| Switch-fuse<br>2.5 a<br> | Disconnector-fuse<br>2.7 a<br> | Switch-disconnector-fuse<br>2.9 a<br> |
| Fuse-switch<br>2.6<br> | Fuse-disconnector<br>2.8<br> | Fuse-switch-disconnector<br>2.10<br> |
| NOTE 1 All equipment may be single-break or multi-break.<br>NOTE 2 Numbers are subclause references of the relevant definitions.<br>NOTE 3 Symbols are based on IEC 60617-7. | | |
| [a] The fuse may be on either side of or in a stationary position between the contacts of the equipment. | | |

**Table 2.** Graphical symbols (IEC 60617-7 2010).

| | |
|---|---|
| Fuse, general symbol<br> | Fuse; Striker fuse<br> |
| Circuit breaker<br> | Disconnecting circuit breaker<br> |
| Change-over break before make contact<br> | Change-over make before break contact, both ways<br> |
| Change-over contact with off-position<br> | Two-way disconnector; Two-way Isolator<br> |
| Contactor; Main make contact of a contactor<br> | Contactor; Main break contact of a contactor<br> |