ELECTRONICS IN LOW-VOLTAGE ELECTRICAL DISTRIBUTION NETWORK: THE NEW APPROACH

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ABSTRACT

Thanks to the possibility of taking advantage of the potentiality offered by electronics properly combined with the traditional electromechanical technology, it is now possible to have a protection system of Low Voltage installations able to certainly ensure total discrimination and also guarantee minimum arcing time wherever the fault occurs.
An infinite level of selectivity steps are also available, regardless of the size of circuit-breaker. This is made possible via a very fast fault detection able to react in a few hundred micro-seconds, together with a simple but quite effective communication system among all circuit-breakers of the distribution chain.
All that being combined with a traditional supervisory and control system, it is possible to obtain a fully automated installation guaranteeing the best performances for the user's safety and for the power supply continuity.
This is a real breakthrough in the field of Low Voltage protection.

Acronyms

ASIC : Application Specific Integrated Circuit
CB : Circuit-Breaker
EFDP : Early Fault Detection and Prevention
EMC : Electro-Magnetic Compatibility
LV : Low Voltage
IL : Inter-Locking
EEPROM: Electrically Erasable Programmable Read Only Memory
MTTR : Medium Time To Repair
ZSI : Zone Selectivity Interlocking

INTRODUCTION

In the ever-evolving field of LV CBs the research has opened up a new horizon where electronics and electromechanical technologies join together to achieve the best results regarding both short-circuit performances and users' safety.
The introduction of electronics has long been experienced on all type of equipment and by all LV CBs manufacturers mainly as self-supplied protective relays in place of thermal and magnetic releases previously used as overload and short-circuit fault protections.
If compared with the previous technology, electronics has allowed self-supplied ground fault protection to be integrated into a single equipment, with a more accurate tripping time for all protection functions and has made it possible to widen the setting range, by programming an even higher number of selectivity thresholds.
Moreover, the implementation of the digital technology together with the communication techniques, made circuit-breakers capable of receiving and transmitting information relevant to the installation status as well as fulfilling automation functions managed by a central supervisory system.
Some reliability problems encountered during the very first experiences, as it always happens when introducing a new technology, have been definitely overcome, as demonstrated by the successful results being obtained since many years.
The new approach consists, as said before, in joining together electronics with more traditional technologies, thus not considering electronics any more as a new, separate technology, but a fully integrated technique for all electrical installation equipment.

Early Fault Detection and Prevention

This paper illustrates a protection system capable of detecting the short-circuit at an early stage (a few hundred micro-seconds), combined with a simple but quite effective system of communication among circuit-breakers.
It guarantees the total selectivity of the installation, wherever it happens, and the reduction of the arc extinguishing time to a few milliseconds (3 to 5 ms), while at the worst, for the first selective CB of the distribution chain (i.e. ACB, In = 5000 A, Icw = 100 kA), to 20 ms.
On account of its characteristics, this new protection system was called EFDP (Early Fault Detection and Prevetion).
Theoretically, EFDP allows an infinite number of selectivity steps, thus solving any problems occurring in LV distribution systems regardless of the size of CBs being connected in cascade. Moreover, EFDP absolutely minimizes the energy associated with the fault and any consequent damages as well.
Minimizing the arcing time and the associated energy is made possible by the tripping time depending only on the mechanical delay of the CB, since the reaction time of the control system is a few hundred micro-seconds, which is definitely negligeable if compared with the milliseconds featured by the mechanical technology.
Further advantages of the new system are:
- reduction to minimum of MTTR of the installation,
- increased operator's safety connected with fault time reduction to minimum,
- important Power Quality improvement thanks to the minimizing of the voltage dips caused by faults

The above mentioned communication system among CBs, although originating from the well known ZSI concepts, represents a great evolution of the technique by allowing reaction times far below the usual ones (about ten or so microseconds vs. some milliseconds as with traditional ZSI), besides being capable of managing the control by a single cable contrary to n cables, one for each protective functions which have to be interconnected in case of a traditional ZSI.

Thanks to its characteristics, the ZSI is used for earth fault and selective short-circuit protections (up to 10 ÷15 In), whereas the EFDP manages almost all kinds of faults including instantaneous short-circuit over the whole range (up to the CB breaking-capacity) and is also suitable when current-limiting circuit-breakers are involved. In fact, this system shows its greatest performances when associated with current-limiting CBs.

It should be noted that, owing to its long time tripping characteristics (an overcurrent might not be a fault), the thermal protection is the only one not affected by EFDP.

While describing EFDP, reference has always been made to a protection system. Actually, it completely changes the protection concept. With EFDP we move from the traditional point-of-view of a CB which trips according to a given current threshold at a defined delay, to a gobal installation approach where any intentional delay is annulled. This shift from local to global approach makes it possible to define EFDP as a "protection system".

EFDP CONCEPT

The damage caused by a short circuit is strongly related to its duration, i.e. the delay from its “birth” till the CB clears it. Traditional low voltage CBs check the current level in each phase plus neutral, and decide to open if the current in at least one of them is above some pre-programmed threshold. For 50÷60 Hz installation, monitoring either the peak or the rms value of the current is a relative slow fault detection process (≤10 ms). Faster detection, however, requires more advanced methods.

ABB has developed an algorithm able to detect a growing short-circuit in few hundred microseconds, including analog to digital conversion of the phase currents plus neutral, noise filtering (to avoid unwanted trippings caused by noise spikes), signal processing and opening command. To validate it, extensive laboratory tests in the most severe working conditions have been performed [see figure 1]. The result is a reliable fast fault detection algorithm capable of detecting a short-circuit in less than 300 μs. For fast reaction time an auxiliary supply is needed.

Figure 1 The algorithm has been validated with different short-circuit test conditions

In order to detect a growing short circuit at an early stage, it is necessary to extract information about the “future evolution” of the current. This can be obtained by looking at the first derivative of the phase current, di(t)/dt, and tracking the connection between the actual current, i(t), and its derivative for all foreseen situations. Under normal operating conditions, the di(t)/dt vs. i(t) curve will soon reach the stable state, forming an oval or a circle in the plane di(t)/dt vs. i(t). The exact shape of the curve varies with load (absolute value and power factor), and the closing angle θ (the source voltage phase angle at which the CB switches on). By plotting all “acceptable” curve shapes for a certain CB, and drawing the envelope curve around them, a non-short circuit area can be defined [figure 2].

To decide whether a short circuit is present or not, each phase plus neutral current is sampled at a high speed. For each input sample, the [di(t)/dt vs. i(t)] status is compared with the pre-defined non-short circuit area, and if the point crosses this area, a growing short circuit is detected. After a short circuit is identified, similarly to the Zone Selectivity interlocking, the CB verifies if other CBs of the distribution chain has detected the same fault. If he understands to be the CB just above the fault, it trips.

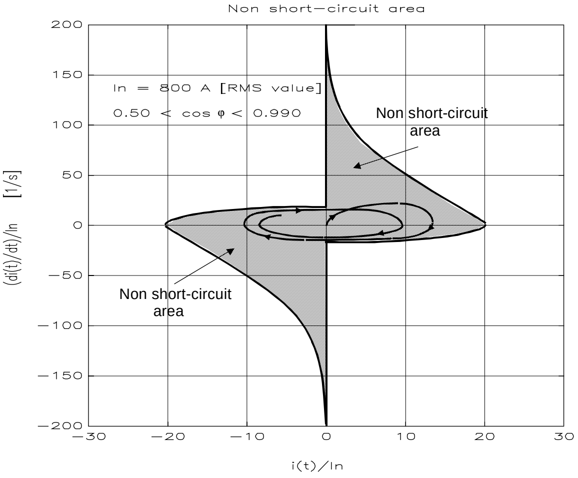

Figure 2a Example of a non short-circuit area and a temporary overload current trajectory

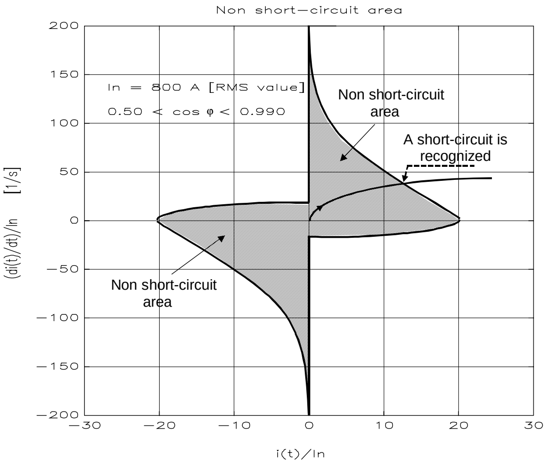

Figure 2b Example of a non short-circuit area and a short-circuit current trajectory

Fault discrimination and isolation (selectivity)

A typical low voltage distribution network, generally follows a hierarchical tree structure, with CBs grouped in switchboards [see figure 3]. The CB size is chosen taking care of the following parameters: the rated current, the breaking capacity and the requested selectivity characteristics of the branch to protect.

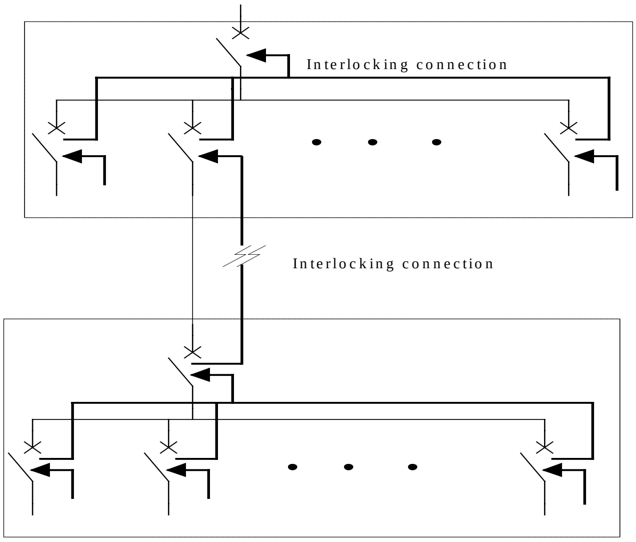

Figure 3 CBs hierarchy with switchboards and interlocking concept

When a short circuit occurs, only the nearest CB above the fault must open. Otherwise, if a higher level CB opens unnecessary large portions of the installation are shut down, causing extra costs. Today, the problem is solved by increasing current thresholds and delay times (frequently increasing the CB size) for each hierarchical level. In case of short-circuit currents that are in the selectivity range (typically up to 15 times the rated current of the CB) the tripping time can be up to several hundred milliseconds; this time is reduced to a few ten or so of milliseconds if the ZSI is used. On the contrary, for short-circuit currents that are over the selectivity zone, the tripping time is faster but the selectivity can be lost.

EFDP avoids the above described inconveniences: combining the fast fault detection algorithm with a unique interlocking (IL) system among the CBs, the total selectivity is certainly ensured, and the tripping time is reduced to a few hundred microseconds indipendently of the hierarchical position of the CB (consequently, reducing damages to the installation).

The interlocking system comprises very fast CB-to-CB communication. Each CB can perform the same fast fault detection, regardless of its position in the hierarchy. When a CB detects a fault, it checks whether this fault has been detected by a downstream (lower level) CB. If the answer is yes, the upstream CB relies on the appropriate downstream CB to perform necessary actions. However, if the upstream CB still “sees” a short circuit after a specified time, it opens, working as back-up protection.

The physical connection can be twisted pair and, if all the CBs are inside the switchboard, no galvanic isolation is needed. On the contrary, in case of two (or more) switchboards, the distance between CBs can be up to 1 km and galvanic isolation is therefore needed.

As with the fast fault detection, auxiliary power supply is used for the IL system.

With EFDP the CB size is determined solely by its rated current and breaking capacity, and not influenced by the position in the hierarchy; more than this, we can also achieve total selectivity between hierarchical levels having CBs with the same size. It has several advantages; first of all, the new concept allows all levels of hierarchy to implement fast fault detection, and the opening command is given in a few hundred microseconds, regardless of the CBs position in the plant. Theoretically (the limit is only given by the accuracy of the current sensors) infinite selectivity levels can be implemented. A special selective short-circuit protection function is no longer needed, and the damages to the installation in case of fault are drastically reduced.

It must also be underlined that the IL system is able to self-monitor its working status: in case of anomalous conditions (for instance, the IL connection is interrupted) the corresponding CB(s) works in stand-alone mode; an alarm is locally present and it can be notified to the central control unit if a communication system is installed.

How EFDP is implemented

To achieve all the functionalities described above, and still being able to offer a competitive product, standard components can not be used to meet the requirements.
An Application Specific Integrated Circuit (ASIC) has been developed to fulfil the needs. The ASIC is designed to operate in different modes depending on whether the auxiliary power supply is present, or not. When it is present, all protection functions are active, and the ASIC is running at

full speed. In this case, the power consumption is not critical. As soon as the power supply disappears, the fast fault detection algorithm, the IL system and communication interface are switched off; the basic functions run with very low power consumption and the traditional selectivity (according to the cronometric and amperometric concepts) is guaranteed. The advantage when using ASIC, is that almost all functionalities reside in one component: power consumption is kept to the minimum and physical space is saved (that means, the number of printed circuit boards needed in the CB is reduced). Reliability and electromagnetic compatibility (EMC) properties are strongly connected to the number of components and interconnects in the electronics. Hence, the CB performance with respect to this, is considerably improved.

In order to give flexibility to the product, the architecture of electronics has been designed using an EEPROM (Electrical Erasable Programmable Read Only Memory) where all the protection parameters including the non-short-circuit area are stored [see figure 4]. Being in a memory, they can be differently defined according to the CB and, more generally, to the installation characteristics.

It must be underlined that, the most of applications, can use default parameters (default non short-circuit area). This makes extremely easy to install and use an EFDP-CB. Because of the thermal protection function is the only one that must be set according to the customer needs, we can affirm that an EFDP-CB based is more user-friendly than the present CBs available on the market.

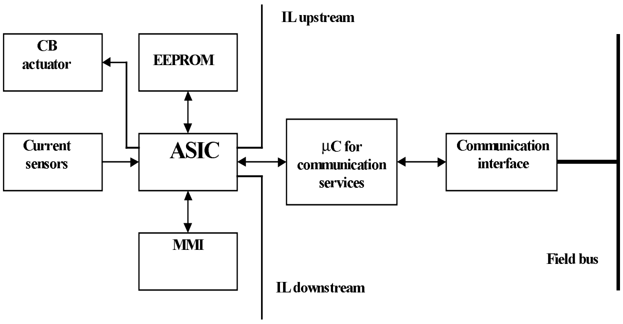

Figure 4 Implementation architecture

Due to the flexibility given by the product, it is also possible to satisfy particular installation requirements by means of customized non short-circuit parameters. They can be easily modified by the user either locally or automatically via the central control system.

WHY USING EFDP

As described above, with EFDP the problem of total selectivity in a plant is definitely solved. The size of the CBs in the installation is no longer dependent on the selectivity requirements. Fast short circuit detection means increased safety, and minimised damages and energy outage for the process. A new implementation approach (ASIC based) with a higher level of integration ensures increased reliability as well as better EMC immunity in a harsh environment.

Table 1 summarizes the advantages given by EFDP when combined with both limiting CBs (generally MCCBs) and selective CBs (generally ACBs)

MCCBs	ACBs
• total selectivity guaranteed	• total selectivity guaranteed
• discrimination and fault isolation inside the whole plant	• discrimination and fault isolation inside the whole plant
• theoretical infinite number of selectivity levels	• theoretical infinite number of selectivity levels
	• fault energy reduction (approximately -90%, worst case)

Table 1

The following example shows a clkear advantage in using EFDP: the comparison is made using an application scheme implemented with a traditional solution and the same application scheme with an EFDP-based solution. It represents a transformer feeder and a main distribution switchboard where total selectivity is present.

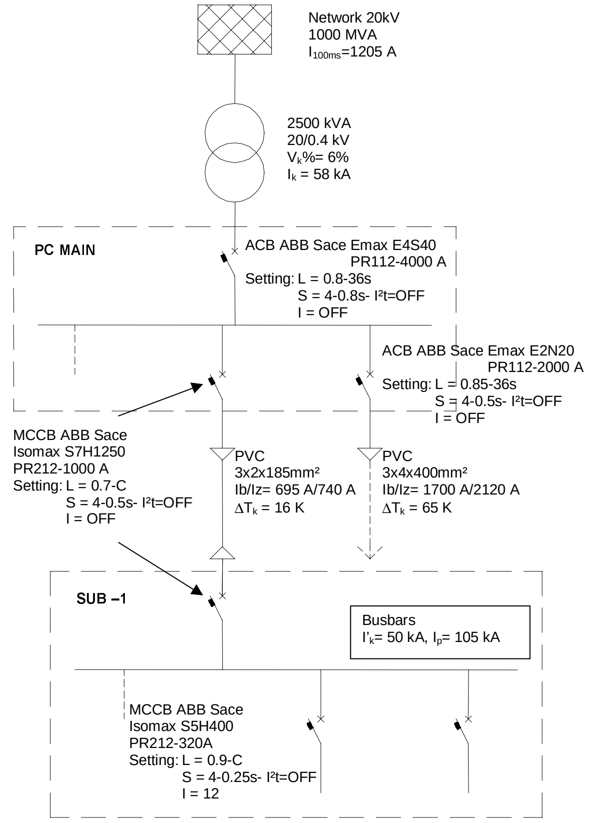

Figure 5a: Traditional solution

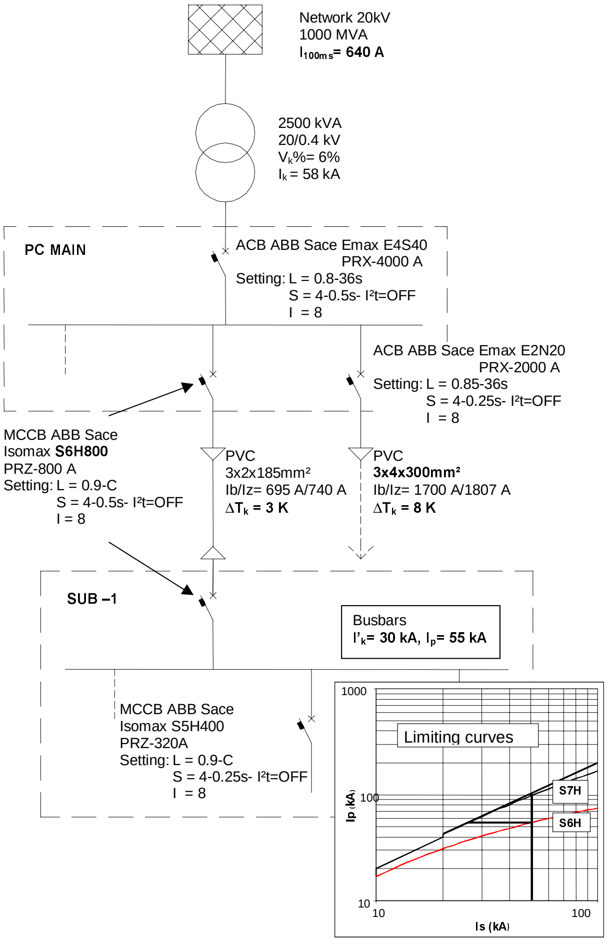

Figure 5b: EFDP-based solution

From a comparison between the two possible solutions (see figure 5a and 5b), it can be noted that the traditional solution requires:

- for the feeder: 4 cables with 400 mm2 cross-section (this cross-section is determined by the equation I2t<=K2S2), which, under short circuit conditions has ΔTk = 65K; in comparison with a solution with EFDP (3x4x300 mm2, ΔTk =8K), and considering for the cable a difference in cost/unit of about 0.175 EURO/mm2 (material + installation costs), this results in an expensive increase of about 70 EURO/m

- a higher protection setting value on MV side: this means, on the distribution switchboard, a more performing busbar system (I'k=50 kA against I'k=30 kA with EFDP) and a main CB with higher ratings (and bigger in size).

OTHER APPLICATIONS

Thanks to the above described flexibility, an EFDP-based electronic device can be used for applications other than the above described. For example, MV application are under evaluation. The non-short-circuit area can be changed so to become strongly oriented to the installation need/characteristics.

Moreover, the use of electronics leads to gain futher important advantages from the point of view of electrical distribution automation.
In fact, electronics allows to better integrate primary and secondary techniques, as well as all secondary functions among themselves.
This can be possible only when:

- currents sensors, CTs or not conventional sensors (e.g.: Rogowsky Coils), are as much as possible integrated with electronics
- all the secondary functions, such as: lines and loads protection, CB control (monitoring of CB status, alarms for protection functions tripping, opening and closing commands), electrical quantity measuring, CB diagnostic and relay self-diagnostic, event recording and communication are integrated in the electronic relay.

The communication, allows to transmit information from local to remote and to connect field units to a SCADA (Supervision Control and Data Acquisition) or a process automation system [see figure 5]. This feature can be obtained by direct connection of the units to the system through a field-bus, without any further cabling or input/output units.

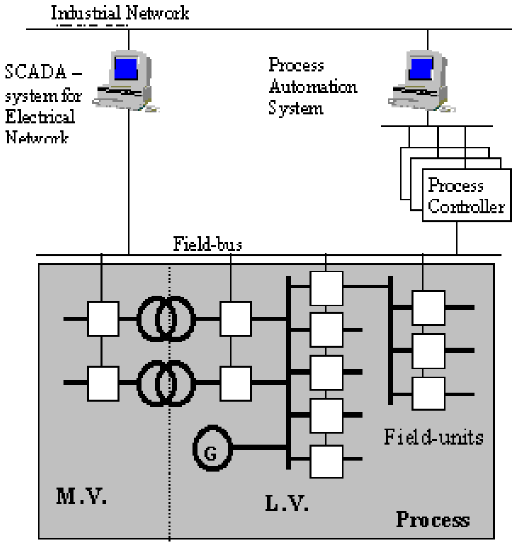

Figure 6: Control system architecture

Combination of advanced functions of EFDP protection system and of connection to an automation system of electric plant, allows to:

- furtherly increase the system reliability thanks to the possibility of checking the general conditions of protection system itself (CBs wearing status, protection status, etc.) and of plant (automatic network configuration owing to fault/maintenance situations or to network load analysis and possible consequent optimizations)
- furtherly reduce fault repairing times thanks to the possibility of detecting immediately on the main computer the faulty plant section.

CONCLUSIONS

ABB SACE's trend towards technological innovation, as shown from many years by the launching of ever-advanced products, has allowed a great breakthrough in the field of integration between the traditional electrical and mechanical technologies and electronics.

An efficient mix of these technologies ensures an optimal protection system for the installation which, in case of fault, allows the best possible decision to be taken since the general status of the installation is monitored and not only the single faulty CB.

All that being combined with a particularly fast fault detection algorithm, leads up to a new way of managing LV electrical systems and is an important item for the evaluation of new opportunities, even for MV installations

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