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Intelligent LV switchboards

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n° 186

Intelligent LV switchboards

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Glossary

Application:
Set of functions executed using hardware and software.

Architecture:
Type of organisation for hardware and/or software components in a system. Also the manner in which functions and processing are distributed.

Bus:
Link used to exchange digital information between the various connected elements.

Communications network:
Synonymous with «communications bus».

Connected device:
Electronic device connected to the bus via a communications interface. Sometimes also referred to as a «station».

CSMA (Carrier Sense Multiple Access):
Method providing random access to the communications network.

CTM (Centralised Technical Management):
System grouping all the applications in a given installation, for example process control, power management or building management.

Decentralised processing:
System in which a part of information processing is carried out as close as possible to the load.

Dependability:
Concept encompassing reliability (of control and monitoring systems), availability (of devices, machines), maintainability (of production resources) and the safety of life and property.

Distributed processing:
Particular type of decentralised-processing system in which processing is carried out in several processing units, each having a certain degree of autonomy and capable of communicating with the other units.

Gateway:
A product enabling data exchange between two different communications networks, without local processing.

Intelligent:
Designates a system with its own processing power and a certain level of operating autonomy with respect to the computer system to which it is connected.

LV:
Low voltage.

Master / slave:
A master regularly polls its slaves and gives them orders.

MCC (Motor Control Centre):
LV switchboard grouping the control and monitoring devices for several motors, valves, etc.

Power management:
Form of technical management specifically intended for electrical distribution systems. The intelligent LV switchboard is a major element in a power-management system.

Protocol:
Sequence of rules that must be followed to establish and maintain data exchange between devices connected to a bus.

Real time:
Designates a control and monitoring system with response times compatible with the requirements of the given process.

Stations:
Information processing devices connected to the bus.

Switchboard central unit:
Unit which centralises all the information available in the switchboard and the direct environment, processes the information and communicates with a supervision system, thus making the LV switchboard intelligent.

Intelligent LV switchboards

In all buildings, regardless of the activity carried out inside, the distribution of electrical power must today satisfy ever-increasing needs for dependability and efficiency.

Energy must be available not only to ensure the comfort and safety of users, but also to avoid the costs incurred by power failures.

Electrical installations must therefore be monitored and be capable of reacting automatically to optimise power distribution. Information processing makes this possible.

Already used in medium-voltage industrial and public-distribution applications, digital control and monitoring is now becoming a reality for low-voltage installations as well.

Starting with an analysis of needs, this «Cahier Technique» takes a close look at how LV power distribution can be managed. Particular emphasis is placed on decentralising and distributing intelligence in and around the LV switchboard. Several examples of such installations are also provided.

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1 Control and monitoring needs

1.1 Introduction

For whatever type of application, whether in office buildings, banks, hospitals, supermarkets, airports, tunnels or industrial sites, the need to monitor and control electrical installations is increasingly prevalent, to ensure the following:

- safety,
- availability of power,
- optimisation of energy consumption and costs (depending on the energy supplier's tariff schedules),
- reduction in operating and maintenance costs;
- ease of operation,
- maintainability and upgradeability of the electrical installation.

Power management can today be implemented by a Digital Control System (DCS) designed to meet all the above needs.

Power management may be combined with the management of other facilities:

- building management (access control, air-conditioning and heating, anti-intrusion systems, lighting …),
- digital control and monitoring of industrial processes.

Due to the wide range of needs and significant technological progress over the last few years, a number of solutions are today available when designing systems to monitor and control electrical installations. It is now possible to arrive at a judicious balance between needs and the corresponding solutions through the use of digital communications buses and the integration of microprocessors in electrical equipment.

«Cahier Technique» n° 156 explains how to design the power section of an electrical switchboard so that it satisfies needs concerning dependability.

The goal of this document is to discuss the optimised design of power-management systems in LV electrical installations.

The first step is to review the needs expressed by users and operators.

1.2 Needs

The needs of users and operators of electrical installations are different, depending on whether the building is intended for commercial, industrial or infrastructural purposes. A hierarchy of needs may be established (see **fig. 1**).

For example, in a small office building, the cost of energy and ease of use of systems by non-specialists are the foremost criteria. On the other hand, in a hospital or a factory implementing an industrial process, the most important need is continuity of service.

Safety of life and property

An electrical installation must distribute electrical power while ensuring the safety of life and property. A power-management system does not replace the primary protective functions (reflex-type devices).

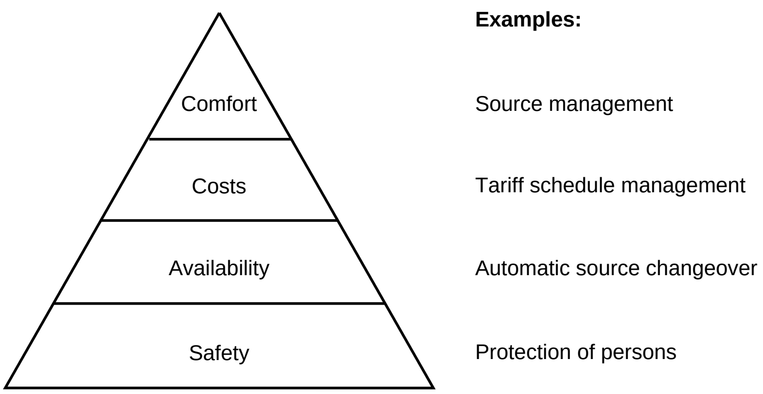


***fig. 1**: hierarchy of needs in LV electrical.*

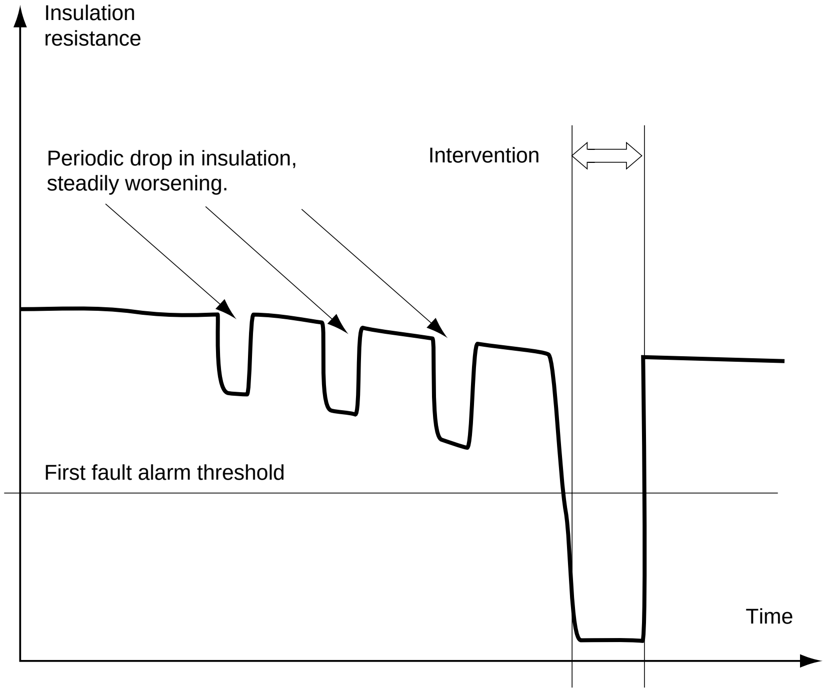


fig. 2: insulation monitoring for an outgoing circuit (IT systems).

Given its capacity to communicate as well as store and process data, it simply assists the operator by indicating the settings of protective devices, the type of fault that caused a device to trip and the status of the installation prior to the incident, etc.

Power management can, however, include overall protective functions. For example, on IT systems, insulation-monitoring may be implemented to warn the operator of a first fault. It is then possible to identify and clear the fault without any break in the continuity of service (see **fig. 2**).

Technological advances have made it possible for operators to reduce the duration of a fault in an installation, thus reducing the probability of a second fault occurring. Operators can check at any time the insulation measurements at different points in the installation and even the evolution of the insulation measurements over time. Preventive maintenance therefore becomes a real possibility. The insulation monitoring function is autonomous and may be considered a decentralised function in the framework of a power-management system.

Availability

Each field of activity has its own requirements concerning continuity of service:

- in hospitals, operating rooms and reanimation centres are designed to provide a high level of dependability,
- in commercial buildings, the widespread use of computer systems has led many people to use uninterruptible power supplies (UPS) installed either locally for individual machines or more centrally for the supply of entire installations with high-quality power,
- in industry, power failures result in production losses. For example, a ten-minute power outage in a Danone factory results in a production loss of 20 000 cups of yoghurt.

The need to ensure the availability of power has led to a number of technological choices for equipment (withdrawable or disconnectable devices or switchboard units, switchboard forms, etc.) and to the distinction in electrical installations between uninterruptible, high priority and low priority circuits, with different choices for the system earthing arrangement.

In this context, the job of a LV electrical switchboard is to manage the sources. To be effective, action taken when a problem occurs must be automatic and immediate.

Managing power failures is one function of power-management systems.

Energy costs

A constant concern for all companies is the need to reduce the cost of energy. Reductions may be achieved by working on two different factors, the level of consumption and the pricing system of the energy supplier. To that end, in-depth knowledge is required on daily and seasonal fluctuations, as well as on power and consumption levels.

A measuring system providing digital data for use on a supervision screen is required to monitor and analyse the above elements.

It is then possible to:

- undertake action to improve the situation,
- check the effects of the action taken,
- determine energy costs per workshop, department, etc.

■ Reduce consumption

There are numerous possibilities, depending on the type of application:

□ turn off lighting and reduce heating in unoccupied rooms,

□ use motors equipped with variable-speed drives for industrial applications,

□ use conditioners and/or filters to reduce losses due to harmonic and capacitive currents in cables and transformers.

■ Reduce costs related to the terms of the contract with the energy supplier

□ use capacitor banks to avoid being billed for reactive power,

□ smoothing peaks in consumption to reduce the subscribed power and avoid overrun penalties. An intelligent system is capable of making optimum use of the subscribed power by shedding certain loads, smoothing peaks and alternating the supply of power to high-inertia loads.

□ Select the best available contract and program production cycles requiring particularly high quantities of electrical power for periods when the cost of power is low. These periods may be a part of the day, the season or the year. For example, certain contracts offer attractive prices if the subscriber accepts to reduce his consumption on a certain number of peak days per year.

□ Use replacement sources. This solution makes its possible not only to have a backup source of power in the event of a failure, but also to smooth peaks in consumption and to avoid moments when the power costs are highest.

Managing consumption and energy costs is another function of power-management systems.

Operating ease

Certain installations are managed remotely, either from a control and monitoring station inside the building or from a centre covering several sites (remote supervision).

Centralisation of management functions is a means to optimise human resources and improve the working conditions for personnel through the use of ergonomic computerised systems and automatic execution of repetitive tasks (programmed operating times for air-conditioning or heating of offices, etc.).

Another consideration is the fact that in office buildings and on small industrial sites, the personnel in charge of the installation is increasingly a non-specialist. The electrical switchboard is commonly under the responsibility of the building watchman or a receptionist. To ensure effective operation as well as for safety reasons, the information presented to these persons must be in the form of a man/switchboard interface that is as ergonomic and simple as possible.

Operating ease is achieved by an electrical installation that is as autonomous as possible (self managed).

Maintainability

The primary mission of the electrical maintenance department in a company is to keep the electrical installation up and running.

There are two types of servicing:

■ corrective action following an operating fault;

■ periodic preventive action.

Maintenance may be enhanced in two ways:

■ by stressing preventive rather than corrective action to avoid breaks in the continuity of service,

■ for preventive level, by stressing conditional maintenance, i.e. action taking into account monitored data, rather than systematic maintenance. The more maintenance is preventive and based on monitored information, the higher the availability of the installation (see **fig. 3**).

Depending on the type of application, the time required to begin servicing and the duration may be very different. They may be very short for industrial processes if there is on-site

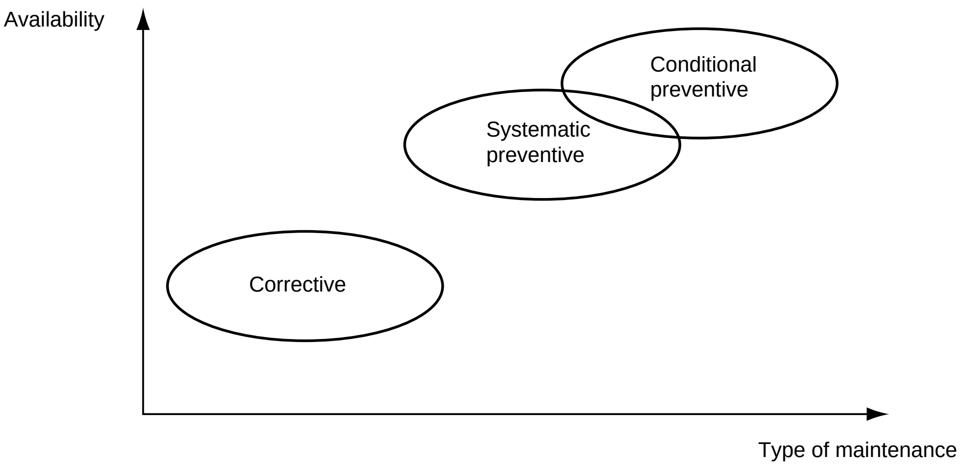


***fig. 3**: operational availability as a function of the type of maintenance.*

maintenance personnel and a stock of spare parts. On the other hand, they may be much longer in office buildings if an outside company must be called in and the spare parts ordered.

The time required to service an installation always depends on the information available:
- when troubleshooting, precise and rapidly available information on the problem and data on installation operating parameters prior to the fault are critical to making the right analysis and preparing the subsequent work (new parts),
- when undertaking preventive maintenance, in-depth information on the installation status makes it possible to intelligently select those elements most requiring servicing.

To carry out effective maintenance, personnel must have relevant information concerning the installation status.
Providing information for maintenance is one of the advantages of power-management systems.

Upgradeability

The points in an electrical installation that are most subject to change are those closest to the final loads. In a factory, the electrical switchboard may be upgraded to keep pace with changes in production facilities. In office buildings, changes in how rooms are used, increasing use of microcomputers, installation of air-conditioning, etc., all result in modifications to the electrical installation.

Improvements in availability and reductions in the cost of the power consumed are also reasons for modifying electrical installations.

To correctly manage these changes, in-depth knowledge of the installation and operating parameters is required.
Power-management systems contribute to easy and effective installation upgrades.

1.3 Functions

Satisfaction of all the above needs by a power-management system requires that a number of devices be installed in the electrical system, generally speaking in order to:
- carry out a number of **automatic actions**,
- provide the operator, either locally or remotely, with the **information** needed **to plan ahead and carry out** the required work on the installation.

These devices provide a number of functions, not all of which are required in a given installation.

Automatic-control functions

- Source management. Loads are supplied depending on the availability of power on the different incomers (source changeover systems, normal and replacement sources, engine-generator sets, etc.).
- Load shedding. Only priority loads are supplied with power when demand exceeds the available level of power on the incomers (for example, when power is supplied by an engine-generator set).
- Time management. To reduce consumption.
- Tariff schedule management. Installation operation is organised to respect the terms of the contract signed with the power distributor (smoothing of peak power levels, special tariffs, etc.).
- Protection of the electrical distribution system. In large industrial installations, system disturbances (transient voltage drops) may, due to the presence of large motors, provoke transient instability phenomena. This function ensures the necessary load shedding to avoid collapse of the entire electrical distribution system.
- Power-factor correction. This function manages the switching of capacitor banks.
- Switchboard safety (over-temperature, internal arcing, etc.).
- Insulation monitoring and fault locating for IT systems.

Information to plan and take action

The purpose of the functions presented above is to make the main LV switchboard autonomous. It is then capable of reacting to various situations to ensure continuity of service and optimal operating conditions.

The second major type of function in an intelligent switchboard is the capacity to communicate information for planning and taking action.
Information includes:
- the status of breaking devices (open or closed),
- measurements (U, I, P, cos φ),
- the settings of protective devices.

These functions require links to:
- a power-management system at a higher level, in charge of managing the entire LV or MV installation,
- a local or remote control and monitoring station,
- where applicable, secondary switchboards,
- where applicable, a process-control system.

Before the operator can be informed and take action (manually reconfigure the distribution system, maintenance, comfort), the electrical switchboard must first communicate with a higher-level system that can be consulted by the electrician and the person in charge of monitoring operation of facilities in the building or factory.

During normal operation, an intelligent (i.e. communicating) LV switchboard is useful in piloting and managing the electrical installation, but it is all the more so when «planning and action» are required in a fault situation.

This is because **corrective maintenance** is more effective if each of the persons involved is rapidly provided with the relevant information. Below is an example of a circuit breaker, communicating via the intelligent LV switchboard, in the event of a fault:

- on the circuit breaker, the information is provided by an mechanical indicator.
- near the circuit breaker, a red light identifies the device that has tripped.
- on a screen at the head of the switchboard, a message in clear text is displayed «10:32:23 - outgoer to Lift 2 - section B - position 12b - tripping due to short-circuit».
- on the supervisor screen of the electrical manager, the same message.
- on the main supervisor screen (e.g. in the security room), a message in clear text is displayed «10:32:23 - Lift 2 out of order due to an electrical fault - call the electrical department on line 347».

Note that planning and taking action also relate to preventive maintenance if the following are available:

- information on the protection and control switchgear in the LV switchboards. This information may be provided by a counter for the number of times a device has opened or closed, a maintenance indicator derived from data such as the sum total of currents interrupted, etc…
- information on the electrical installation, for example, the number of hours the supplied loads operate, drops in insulation…

2 Current solutions

2.1 Currently used solutions

The functions presented in chapter 1 are already available, either in whole or in part, using a number of different technical solutions:
- in industry, by adding electrical management to the facilities already implemented for industrial-process control,
- in commercial buildings, by including electrical-distribution management systems in the existing building-management systems.

Consider the solutions implemented for a motor control centre (MCC) or a main low-voltage switchboard (MLVS).

Solution implementing PLCs

- PLCs and wired connections

The first step toward an intelligent switchboard involved the use of industrial PLCs (Programmable Logic Controllers) near the switchboard.
The PLCs serve as interfaces between the switchboard and the technical management system and are capable of carrying out certain automatic-control functions.
Made up of racks filled with input/output boards, the PLCs are wired to the various sensors and actuators of an electrical switchboard.
A specialist is required to program the PLCs and each application is the result of a specific development.

This type of solution is subject to the following limits and constraints:
- great quantities of control wires between the switchboard and the PLC, with the following disadvantages:
  - very high wiring costs;
  - a large number of terminal blocks which increase the volume and notably the footprint of the switchboard;
  - high risk of latent defects due to the many connection points;
  - risk of malfunction due to the very strong magnetic field created by a short-circuit on an outgoer;
- significantly reduced capacity for installation upgrading, due to the very specific nature of the PLC programming which can rarely be modified by the in-house electrical department,
- a data-processing system poorly suited to the given applications in that the main task of a PLC is to continuously poll the status of devices which in this case often remain in the same position year round.

- PLCs and remote input/outputs

In the past few years, PLC manufacturers have taken advantage of dropping costs in microelectronics and communications buses and developed remote input/output modules, thus making it possible to reduce the quantity and cost of wiring.
This solution has been put to very little use in the field of electrical switchboards because it is poorly suited to the constraints inherent in the field, notably the thermal environment, electro-magnetic disturbances, the need to control switchgear locally, etc.

Solution implementing automated switchboards

In the 1980's, a number of offerings were developed by the major panel builders for applications in continuous-process industries or in large commercial buildings.

These offerings differ from the solutions presented above in two aspects:
- the development of specialised modules wired to the switchgear components and communicating via a parallel link or a serial bus with a PLC installed at the head of the switchboard. These modules, designed for use exclusively in switchboards produced by specific panel builders, are installed on the front panel of the switchboard and include built-in local control and status-indication functions.
- the development of repetitive functions for the electrical automatic-control systems. For example, source changeover systems with load shedding and reconnection of outgoers.

These systems are characterised by decentralised data processing in the switchboard and the fact that the functions can be handled by electricians. What is more, they contribute to the massive reduction in the quantity of wiring inside the switchboard.

The limited success of this type of system is due to the fact that these modules were specific to the different panel builders.

Communicating components

Microprocessors are now used by manufacturers of electrical equipment to:
- improve the performance of their products. A good example is the widespread use of electronic trip units in circuit breakers. The latter are increasingly capable of communicating the data they process via digital buses.
- enhance their offering with new functions, for example, power and energy measurements at a

given point in an installation, with the capacity to communicate the data.
In parallel, automatic-control functions such as source changeovers or reactive power regulation continue with their own developments.

The increasing use of such products and modules in electrical switchboards has resulted in a considerable increase in the quantity of information that can be transmitted to a centralised supervision system. In large-scale applications, the engineering firm in charge of the entire installation is still obliged to implement a complex communications architecture with intermediate levels fulfilling a dual mission:

- sorting and analysing the available information,
- providing communications gateways between different buses.

2.2 Advantages and disadvantages of these solutions

The three types of solution presented above were developed over the last ten years to satisfy some of the needs listed in chapter 1.
Their advantages and disadvantages are summed up in **figure 4**.

In conclusion, the following may be observed concerning the currently implemented solutions:

- a tendency, well underway, toward decentralisation of automatic-control functions and data processing for electrical switchboards,
- a hierarchical structure for data flow,
- the need for specific development work and, consequently, for specialists.

In the electrical-switchboard field, decentralisation of data processing has been made possible by digital communications buses.
This is the case for:

- industrial-process control and monitoring. PLCs with hundreds of input/outputs first gave way to PLCs with remote input/outputs and are now gradually being replaced by networks of PLCs and micro-PLCs positioned as close as possible to the controlled sensors or actuators. The near future will see networks comprising «intelligent» sensors and actuators,
- building management. Functions have now been standardised and are carried out by specific products well suited to needs. Solutions providing industrial-process management, building management and electrical-distribution management are now dedicated systems built around decentralised architectures that increasingly incorporate distributed intelligence (see **fig. 5**).

A notable aspect of low-voltage electrical switchboards is their great diversity and the wide range of functions that they must provide. On the basis of existing solutions described in this chapter and that have already been put to use, it is today possible to determine a number of principles that define and specify what is understood by the term «intelligent switchboard» and the corresponding control and monitoring system.

- An «intelligent switchboard» is defined by its capacity to autonomously carry out the functions assigned to it and to fit into the control system of an electrical installation.
- To handle the wide variety of installations, the design of the switchboard must be based on the following principles:

	PLC-based solutions	**Automated switchboards**	**Communicating components**
Weak points	Specific to each application, little capacity for upgrading	Solution available only to large panel builders	Single-function solutions
	Large quantity of wiring	Requires PLC specialists	Increase in the number of modules
	Requires PLC specialists		Requires electricians specialised in communications
Strong points	Reliable equipment, used on large industrial sites	Implementation of the decentralisation concept	Reliable field-bus technology
	Solutions perfectly tailored to the initial needs of each customer	Functions may be mastered by an electrician	Industrial products capable of withstanding EMC constraints in switchboards
		Functions standardised with progression of projects	

***fig. 4**: advantages and disadvantages of traditional solutions in meeting control and monitoring needs.*

- design must be modular in terms of both hardware and software,
- decentralisation of processing must be optimised,
- functions and products must be standardised, designed for installation and implementation by an electrician and capable of handling the severe environmental conditions prevalent in an electrical switchboard.

■ For users confronted with automation needs and the necessity of obtaining relevant information, an intelligent switchboard provides:

- an enhanced level of dependability and upgradeability,
- standardised solutions, even for large sites,
- cost reductions and simplified implementation,
- easier operation and maintenance.

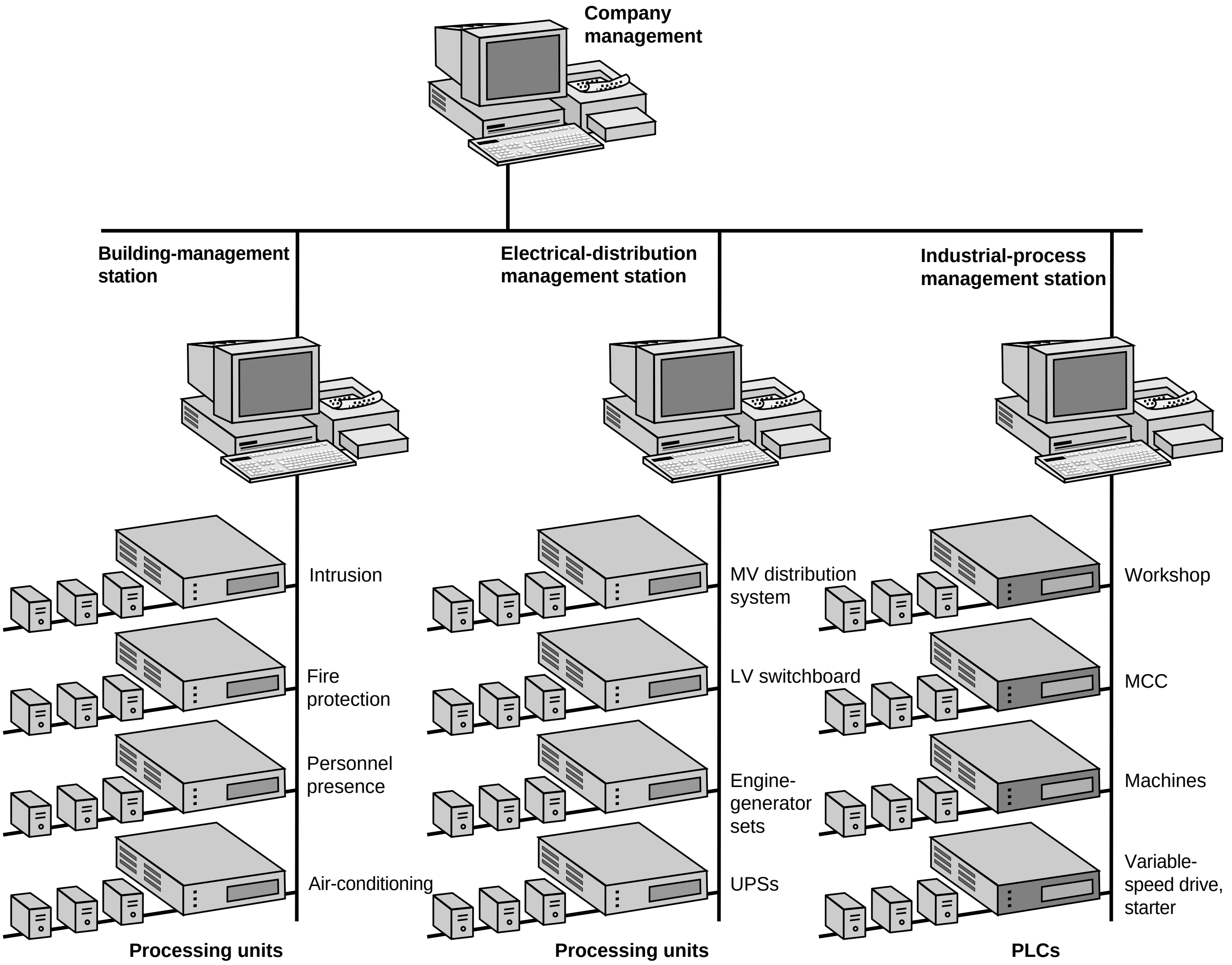


fig. 5: decentralised architecture for building management, electrical-distribution management and industrial-process management systems.

3 Intelligent switchboards

Intelligent switchboards, as defined in the preceding chapter, are based on the concept of decentralised architecture with distributed intelligence.
After defining these terms, we will go into how the various functions of an electrical installation may be decentralised and distributed in the best possible manner, whether for an entire installation (power management), for a low-voltage switchboard or for a given outgoing circuit.
Then the criteria determining the selection of an internal communications bus for the LV switchboard, suited to the given needs, will be examined.

3.1 Definitions - decentralised architecture and distributed intelligence

■ An analogy based on how companies are organised may be useful in understanding these two terms.
In centralised organisations, all decisions are made by the «boss». Subordinates provide him with all information and wait for orders.
In an effectively decentralised organisation, a majority of decisions are delegated by the boss to the subordinates. Each person, within the limits of the delegated powers, acts autonomously and reports only the necessary information back to the boss. Only those functions concerning the entire company are centralised, for example, the payroll.
Finally, a given function may be distributed between a number of subordinates. This form of organisation implies information exchange and a certain degree of autonomy for the team in charge of the function.

■ **Figure 6** shows how a function may be:
- totally decentralised,
- partially decentralised, whereby execution of the function is decentralised, but parameter settings remain centralised and common to a number of functions,
- distributed among equipment on the same hierarchical level.

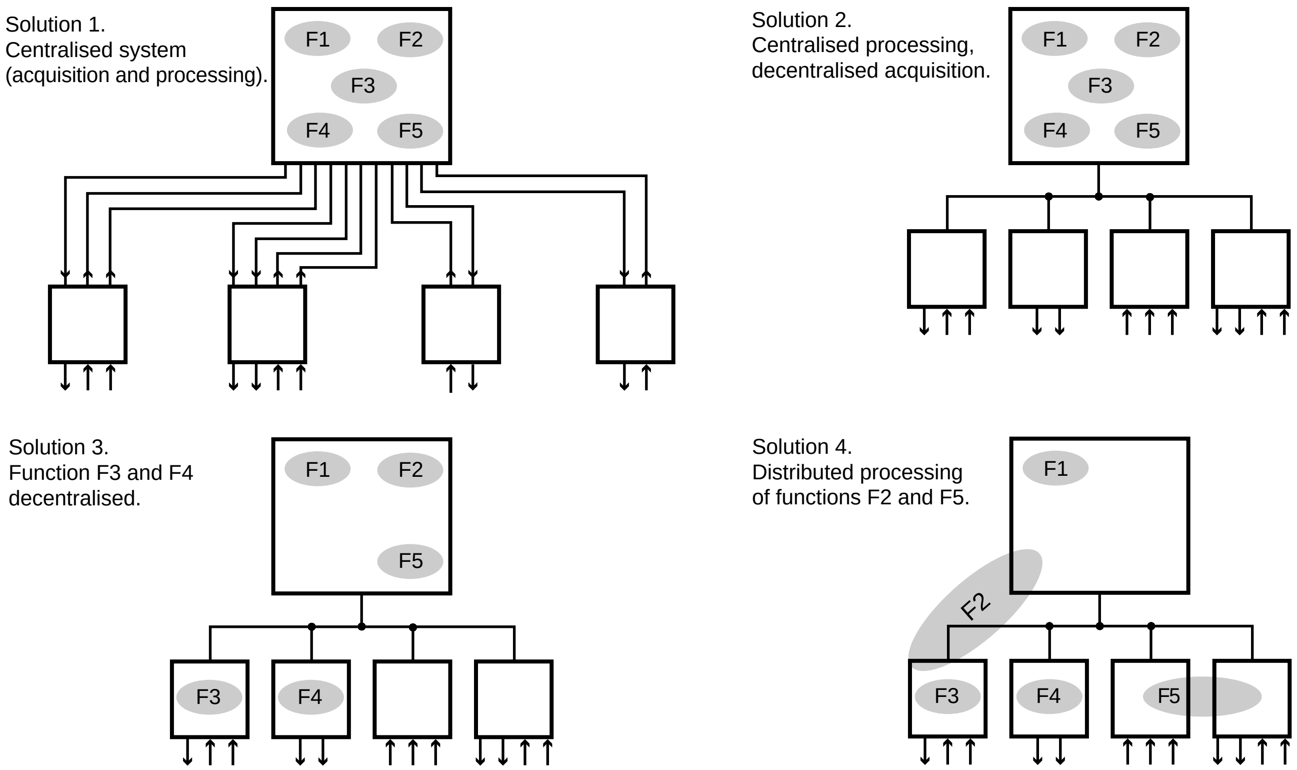


fig. 6: possibilities ranging from a fully centralised to a decentralised system with distributed intelligence.

■ Decentralisation as implemented in a company may be applied in a similar manner to the control and monitoring system of an electrical installation. The Centralised Technical-Management (CTM) concept is now giving way to the decentralised power-management concept with distributed processing.

Note that high-power distribution systems (architecture and protection) follows the same principles, thus ensuring coherence between high- and low-current systems (see **fig. 7**).
Below are examples of these concepts applied to different electrical functions.

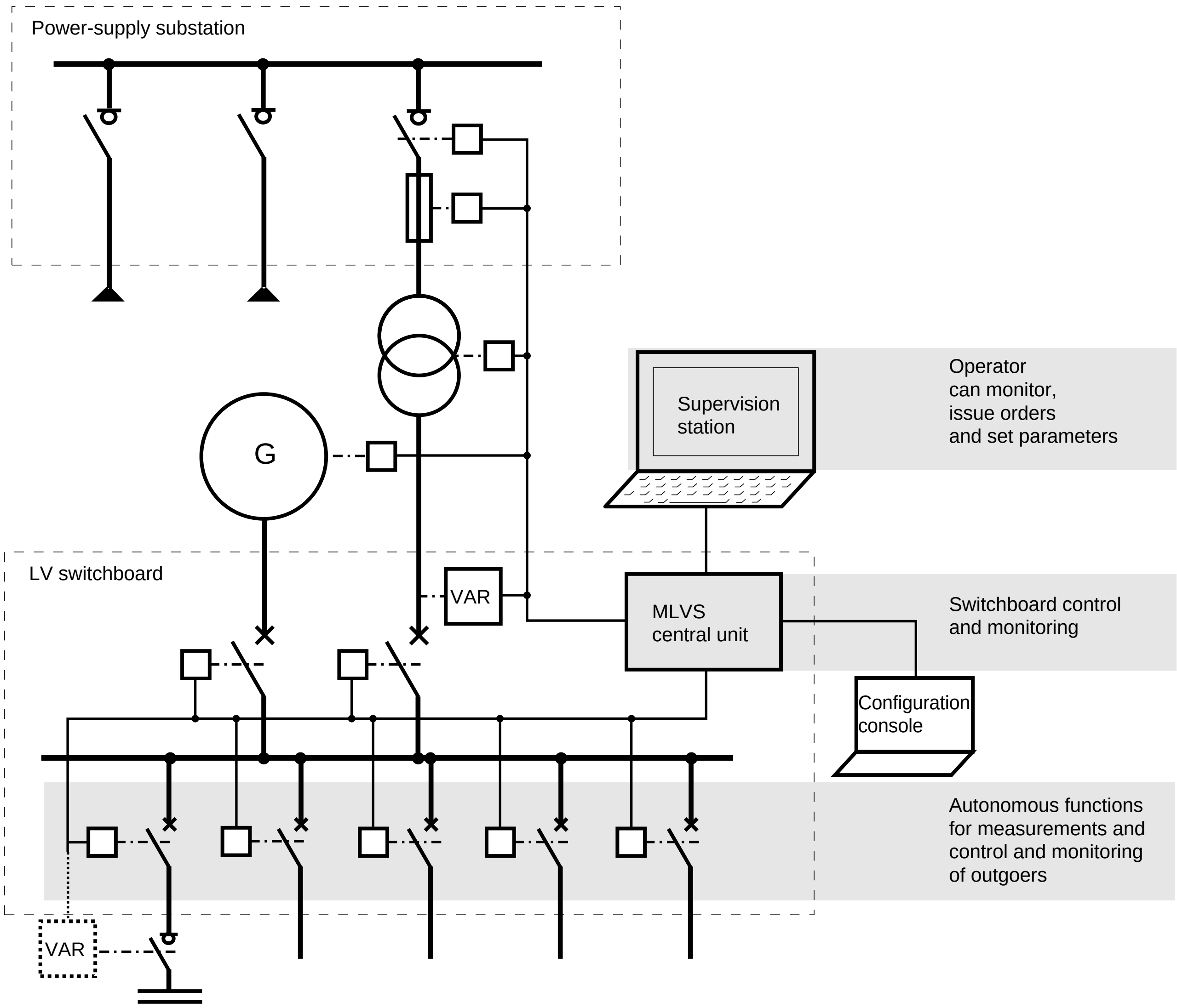


fig. 7: small to mid-sized installation with a control and monitoring system (power management), of which the major part is located in the MLVS.

3.2 Decentralisation of functions in an electrical installation

Energy contract management
This type of function requires an overall view of the installation.

In many cases (small and mid-sized installations), the LV switchboard is the central element in the installation. If this is the case, the contract-management function is handled by the LV switchboard central unit, with either local or remote (from a supervision station) parameter settings. On a large site (medium-voltage distribution system), switchboards receive operating orders from a higher-level system.

Time management of outgoers

In centralised systems, this function is traditionally assigned to the supervision station which can be used to set operating-time parameters for outgoers and to issue opening and closing orders for devices. On the other hand, in a decentralised power-management system, these commands are executed at the level of the switchboard central unit or even at each device. A device must simply receive the operating set-points and be equipped with an internal clock that is regularly synchronised by the supervisor.

In **figure 8**, the information flow is shown for a traditional centralised solution and a decentralised solution. It is clear that the permanent information flow is reduced as decentralisation is increased. On the other hand, new data exchanges, much more limited in scope, are required to periodically synchronise the various internal clocks and transmit new operating set-points.

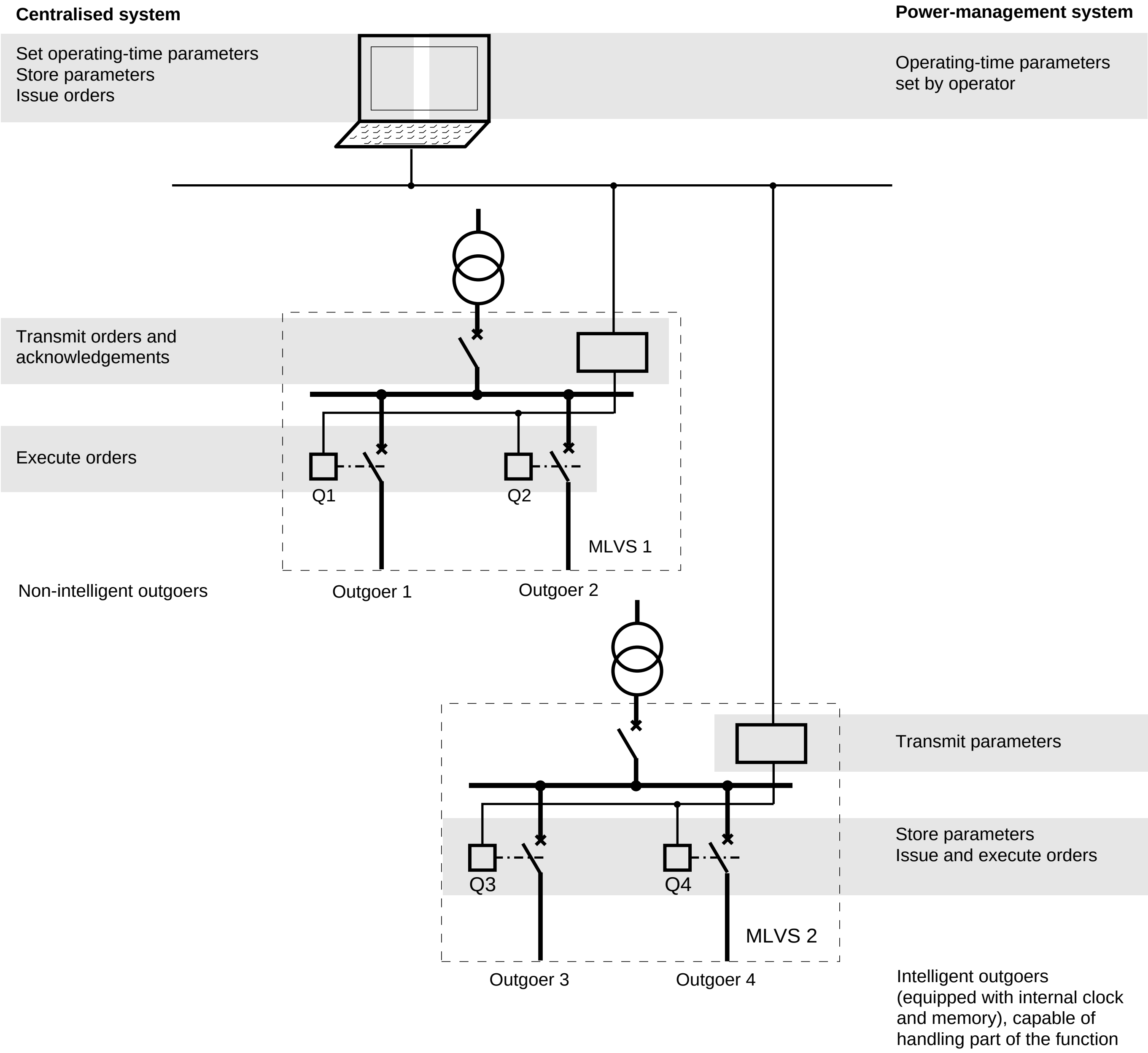


fig. 8: time management of outgoers, in a centralised system (CTM) and in a decentralised and distributed system (power management).

Source management

This function opens or closes the incoming circuit breakers in the switchboard, depending on the data processed either in the switchboard or in the immediate proximity. It is therefore perfectly logical that the operations required for this function be carried out in the electrical switchboard. Note that in relay-based systems, the relay sub-assemblies were installed in the switchboard and the diagrams were drawn up by the panel builders. It was only when a new technique arrived, one that most panel builders could not handle, that this processing was remoted to a centralised PLC.

If the incoming diagram is simple, for example with a normal and replacement source, this function is totally decentralised and is carried out by an autonomous standard product. If the incoming diagram is more complex or requires programmable shedding of outgoers, the function is located at the level of the switchboard central unit:

- if the replacement source supplies the main LV switchboard alone, a switchboard central unit will carry out the function autonomously (see **fig. 9**),
- on the other hand, if the replacement source supplies the MV system and/or several MLVSs, this function is distributed between the MV switchboard central unit and the central units of the various LV switchboards.

Reactive power regulation

Power-factor correction using capacitor banks is an independent automatic-control function built into a product called a reactive power regulator. This type of regulator must operate autonomously in over 90% of all installations.
A communicating reactive power regulator can be built into a power-management system to provide the following additional useful functions:

- setting of parameters from a supervision station,
- action on alarms processed by the switchboard central unit,
- action on maintenance information in the framework of overall switchboard maintenance,
- coordination of the reactive power regulation function with other switchboard functions. For example, during operation on an engine-generator set, the capacitors must be disconnected. This can be carried out by opening a circuit breaker upstream from the capacitor banks or by transmitting a shutdown order to the regulator if it is connected by bus to

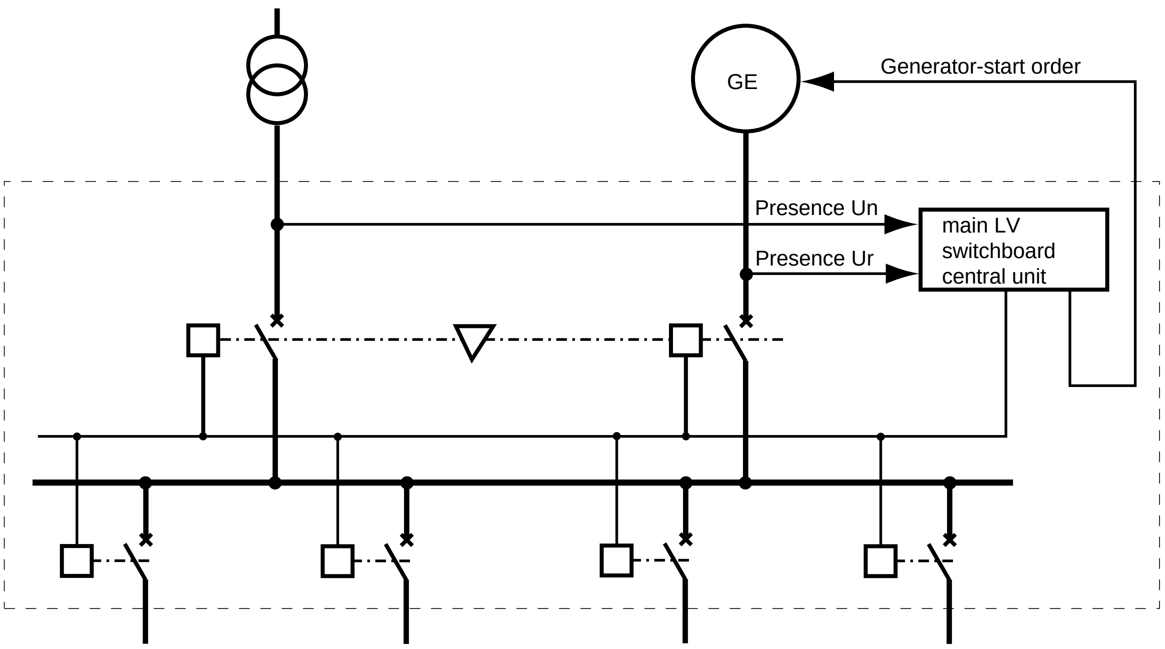


fig. 9: example of source management. With this solution, the switchboard central unit manages the outgoers. Priority outgoers are progressively reconnected during operation on an engine-generator set. Definition of outgoers as priority or non-priority is adjustable. Note that it is not necessary to separate the busbars into two parts, thus eliminating the coupling device. Finally, this solution makes it possible to handle multiple-incomer diagrams with great ease.

the switchboard central unit managing or monitoring source changeovers.

Threshold-initiated load shedding

In certain situations (voltage drop due to a problem on the distribution system, failure of a source, demand exceeding the available power from a source supplying the switchboard, etc.), it may be necessary to rapidly shed a group of non-priority outgoers, for example to avoid transient-stability problems.
Figure 10 shows how shedding of non-priority outgoers is processed in a decentralised manner, following an overload on the main LV switchboard.
This example shows that the amount of information exchanged is very small. The central unit receives a signal, issues an order via the bus and the concerned circuit breakers carry out the order.

Management of an incomer or an outgoer

Management of an incomer (or an outgoer) may include some or all of the following functions:
- control and monitoring (control of the device and monitoring of its status),
- measurements (currents, power levels, energy drawn, etc.),
- local or remote operator interface,
- communication with the switchboard central unit.

By distributing these functions among different modules (see **fig. 11**), it is possible to solve certain problems:
- not all the outgoers require all the functions listed above,
- the operator interface can be remoted,
- the interface must be adaptable to the various users (language, level of competence, etc.).

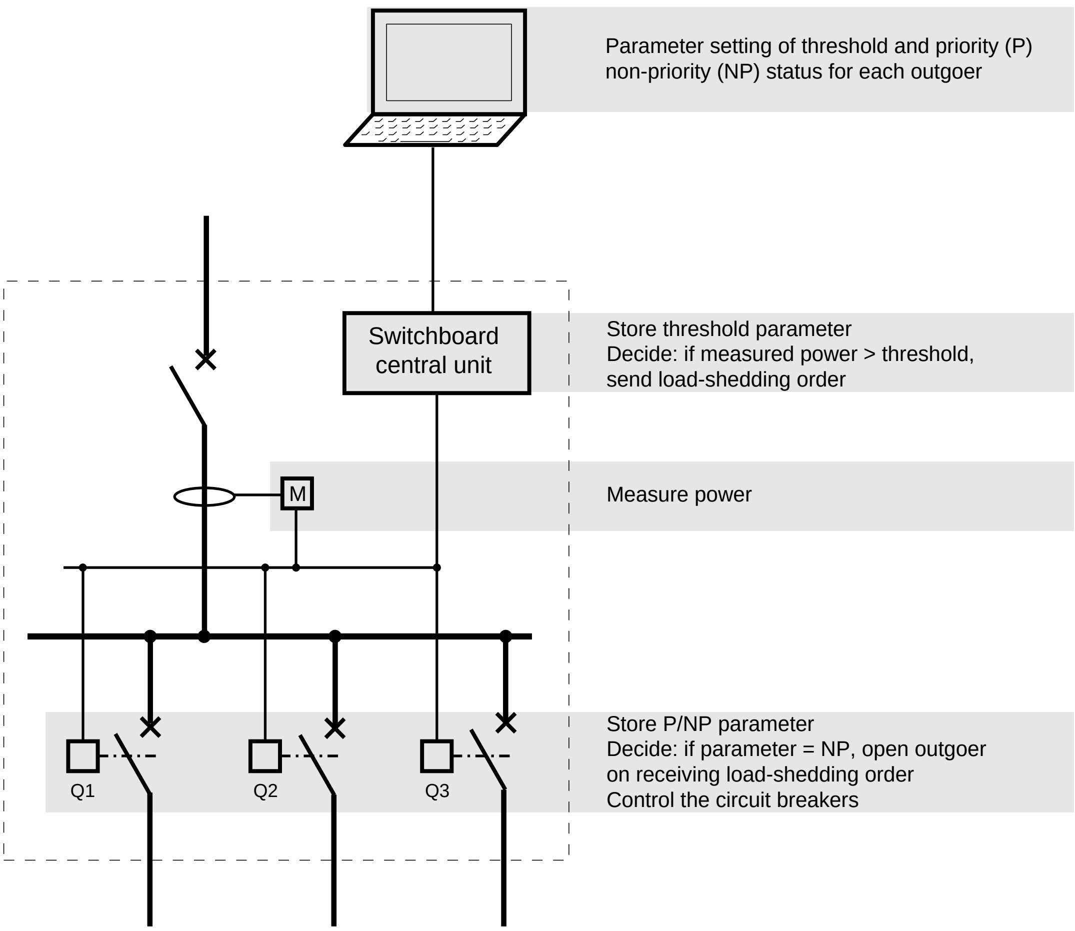
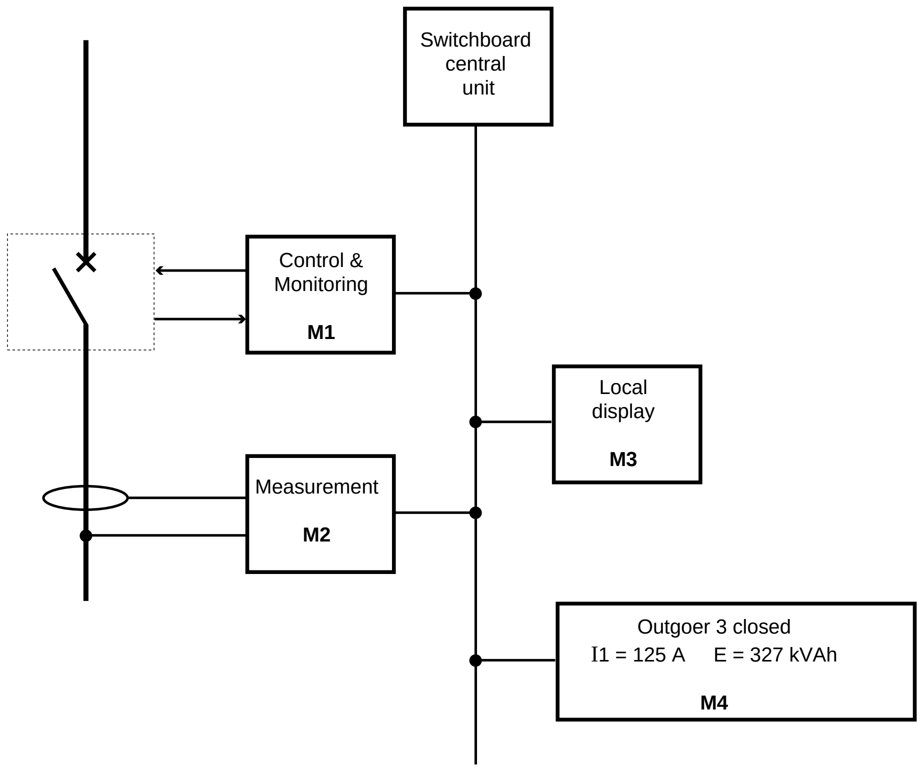


***fig. 10**: example of decentralised processing of a load-shedding order.*



Module M1 controls the device and reads its status conditions.
Module M2 measures the currents and voltages and prepares the power and energy information.
Module M3 displays the status and measurement information for the outgoer on the front panel of the switchboard. It can also control the outgoer.
Module M4, identical to module M3, is a display remoted to a point outside the electrical room. The information may be displayed in a manner different than on M3

fig. 11: example of distributed processing for outgoer management.

3.3 Advantages of decentralised architecture and distributed processing

Mastering complexity

A complex problem can often be broken down into a set of simple basic problems. Similarly, controlling an electrical installation may prove very complicated given the size of the installation and the number of functions that must be processed. By decentralising a majority of the functions, most of the processing can be carried out by smaller units. The processing is then easier to handle and can be standardised. The concept of type-tested assemblies, already used for the power part of electrical switchboards, can now be expanded to include power-management functions. The load on the higher-level processing unit is significantly lightened and it can devote its processing power to the tasks for which it is specifically intended.

Technical and economical constraints

As already mentioned in the preceding chapter, the considerable increase in the quantity of information to be transmitted has led to the development of hierarchical architectures. Just as in large installations where there are levels in the power-distribution structure (main and secondary LV switchboards, final distribution enclosures, etc.), the creation of levels for the processing of information is the best solution:

- constraints (response times, environment, throughputs, etc.) are not the same inside a switchboard and throughout an entire installation,
- all the information that is useful for a function at a given level is not necessarily relevant on a

higher level, for example, all the information available locally on each device is not necessarily of great use to the operator:
□ some information is intended strictly for maintenance purposes,
□ other information must be summarised to avoid submerging the operator (see **fig. 12**),
□ the cost of programming is reduced by using standard «codes» for a vast majority of the functions.

Continuity of service

In a centralised system, a breakdown results in an interruption of service for the entire installation. In a decentralised system, however, the same breakdown can be limited to the single subsystem where it occurred, thus enabling the rest of the installation to continue operating, though perhaps in a downgraded operating mode. For example, if maintenance is required on the switchboard central unit, local functions inside the switchboard remain operational, given the decentralised nature of the installation.

Information	User	
	Maintenance room	Supervision station
Device position	X	X
Faulty outgoer	X	X
Energy measurement		X
Outgoer not available (summary)		X
□ Disconnected/locked out	X	
□ Not supplied	X	
Trip unit setting	X	
Load shedding in progress	X	X

***fig. 12**: example of sorting information to be made available to different users.*

Maintainability

A decentralised system implements a large number of processing units, however, their failure rate is not cumulative.

The limited number of connection points reduces the number of breakdowns.

The self-test system on the digital products and the communications buses can detect nearly 100% of possible breakdowns.

Flexible implementation

■ Setting up a new site often takes place over relatively long periods. It is not uncommon that for budgetary reasons, the remote supervision station is installed one or two years after commissioning of the switchboards. The latter can, nonetheless, operate autonomously over such long periods if decentralised processing is carried out locally.

■ When existing installations must be renovated, upgrading can be spread out over several years. Decentralisation makes the replacement of a switchboard simpler. The new switchboard can be factory tested and a single serial link is all that is required to connect the new switchboard to the control system.

3.4 Conclusion on decentralised processing in a LV switchboard

The examples presented in chapter 3 show that the functions managed by an intelligent LV switchboard can be distributed to varying degrees among different processing units.

■ Certain functions are handled by the switchboard central unit when:
□ the processing is complex and cannot be carried out by a standard autonomous module. For example, source management when there are multiple incomers,
□ the functions call on processing that is common to other functions. For example, a source changeover can be caused by the failure of the normal source or by an order issued by a contract-management function,
□ the functions must be coordinated with other equipment. For example, when management of replacement sources brings MV equipment into play.

■ Certain autonomous functions can be carried out by dedicated products that have been optimised for the given function. This is the case for reactive power regulators and source changeover units.

When these autonomous products are incorporated in an intelligent switchboard, they can be connected via a bus to the switchboard central unit which provides additional functions such as:
□ setting of parameters for the products by a more user-friendly device that is common to all the functions carried out in the switchboard,
□ minimum management during downgraded operating modes,
□ incorporation of the products in predictive- and corrective-maintenance functions.

The various functions mentioned in this document may be included in the architecture presented in **figure 13**:

■ The switchboard central unit is in charge of:
□ processing the general switchboard functions and the interdependent functions,
□ coordinating the functions managed by lower-level modules,
□ integrating in a higher-level control system,
□ communicating with a terminal intended for the electrician in charge of implementation and maintenance operations. During servicing, this terminal is connected locally in front of the

switchboard. In no way does it replace the centralised supervision station from which the operator manages the installation.

■ Certain modules are in charge of processing autonomous functions (reactive power regulation, insulation monitoring, etc.).

■ Other modules are in charge of managing an incomer or an outgoer.

Modularity makes it possible to:

□ integrate control and monitoring in the concept of tested, standardised functional units,

□ standardise connections between the module and the switchgear, thus reducing the risks of breakdowns due to faulty connections,

□ take action on a given outgoer without shutting down other elements in the switchboard, in the event of a breakdown or installation upgrading.

The modules and the switchboard central unit are connected via a digital bus. Note that use of this type of bus offers a wide range of advantages:

■ massive reductions in the quantity of control wires in the switchboard and consequently in the cost of wiring and the space required,

■ reduced risks of breakdowns due to faulty connections

■ less design and wiring time for the panel builder,

■ greater installation upgradeability, for example, the addition of outgoers or functions in an existing installation.

The next chapter describes the types of buses best suited to power management applications.

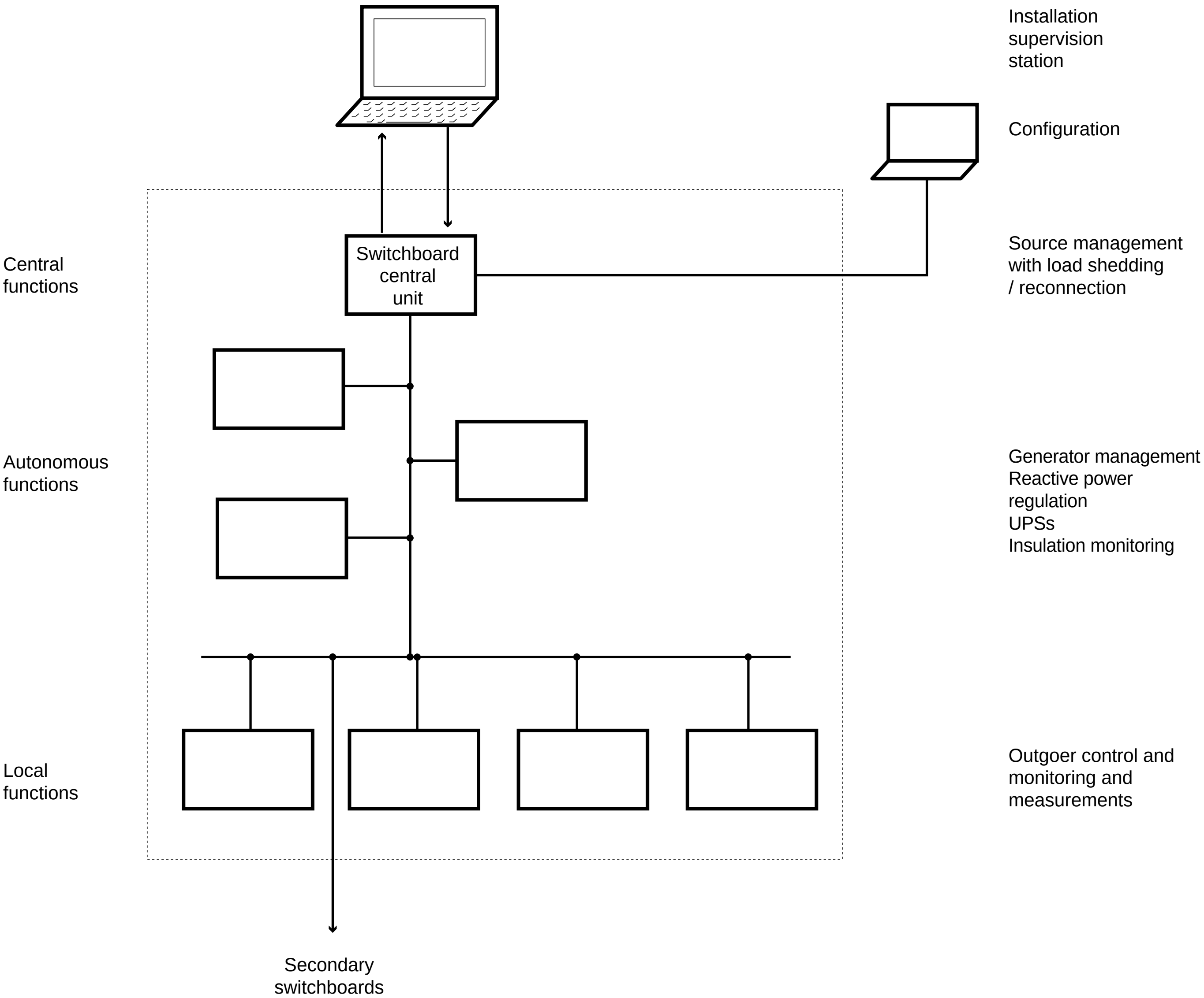


fig. 13 : distribution of functions in the architecture of a switchboard.

3.5 A switchboard bus suited to electrical applications

Before selecting a suitable field bus, it is essential to fully comprehend the constraints weighing on an electrical application, notably the information flow, response times, the environment, etc.

Characteristics of an electrical application

■ A naturally stable and continuous application
The purpose of an electrical installation is to distribute power to each load. The purpose of an LV switchboard is therefore to permanently maintain the operational status of outgoers.
Opening of a device may be related to one of the following events:
□ reaction of a protective device to an electrical fault,
□ operator intervention to isolate a circuit (for servicing, to turn off the lights on a floor at the end of the day, etc.),
□ intervention of an automatic-control function to shed non-priority loads, for example, following the failure of the normal source.
The change in status of a device is therefore an exceptional event. An electrical switchboard is continuously in a naturally stable state. Note that circuit breakers are by nature bistable devices.

■ Certain situations cause an information avalanche
On the other hand, certain situations may result in an avalanche of information over very short time periods. For example, following the failure of the source supplying the switchboard, mono-stable devices such as contactors simultaneously open and the automatic source changeover and load-shedding functions issue orders to the circuit breakers.

■ Limited real-time constraints
In an electrical installation, the response time of the system to an event depends on the nature of the event:
□ when the operator issues an order from the supervision station, the system must respond within an time delay that is «acceptable» to the operator, i.e. one or two seconds between confirmation of the order by the operator and the change in status of the device displayed on the screen,
□ for source-changeover automatic-control functions, no specific constraints concerning the response time weigh on the application. The goal is simply to reduce to the strict minimum the time that the loads are not supplied with power. Response times of several hundred milliseconds are perfectly reasonable
□ if, during operation on an engine-generator set, the rated output of the set is overrun, certain non-priority loads must be shed. The authorised overload time is indicated by the manufacturer of the engine-generator set and depends on the level of the overload.
In complex installations where local power generation facilities are coupled with the power supplied by the utility, in the event of a utility failure, certain loads must be shed in a fraction of a second, before the engine-generator set protective functions can react.

■ Data flow capacity sized for the number of measurements
Electrical measurements may result is a constant flow of information on the switchboard bus. The most common measurements concern voltages, currents, power levels and quantities of energy.
Sizing of the bus therefore depends not only on the quantity of information that must be transmitted, but above all on how often the information must be transmitted:
□ measurement values for currents or power levels may be used by the operator to monitor the distribution system in real time and the values may therefore have to be transmitted every few seconds,
□ values concerning the quantity of energy consumed are required only every few minutes, at most, i.e. the frequency of transmission for these values is very low.

■ Implementation constraints in an electrical switchboard
Installation of a bus inside an electrical switchboard must take into account the following constraints:
□ the bus must not be sensitive to the major electromagnetic disturbances that exist in a low-voltage switchboard,
□ it must be easy to install during wiring of the switchboard and be easily modified during switchboard upgrades,
□ the cost of each connection point, which is a decisive element in selecting a bus in that a low-voltage switchboard comprises great numbers of connection points.

Master/slave protocols are inadequate

For the solutions discussed in chapter 2, master/slave protocols are commonly used. An example is ModBus (for further information, see «Cahier Technique» n° 147).

For a basic automated switchboard, i.e. one that manages only orders and acknowledgements, a master/slave protocol is sufficient to satisfy the required functions. For example, given a switchboard with 50 incomers and outgoers and a polling time of 20 milliseconds for each one, approximately one second is required to poll all the incomers and outgoers. When an event occurs (order from the supervisor or intervention of an automatic-control function in the switchboard central unit), polling of the status of each incomer or outgoer can be interrupted to send the necessary orders.

But when the system functions require the transmission of measurement values, the weaknesses of master/slave protocols, i.e. the increased time required for each polling cycle, rapidly become apparent.

What is more, when a device-status change occurs following tripping, the information is made available to the switchboard central unit only during the next polling cycle.

Finally, this type of protocol is inadequate for distributed processing because the central unit can act as the master only if all the information runs through it.

CSMA protocols

Contrary to protocols using the master/slave access method, CSMA (Carrier Sense Multiple Access) protocols allow the various stations connected to the bus to spontaneously transmit data only when there is a real need.

■ CSMA constraints
Random access to the bus creates three constraints that do not exist in master/slave systems which are, by definition, centralised. Solutions for these difficulties are easy to implement.

□ Risk of collision. Several connected stations may transmit data simultaneously. Rules are set up to avoid collision between the different messages.
Two different solutions exist:
- CSMA-CD (Collision Detection). Using this technique, the stations detect the interference on the bus due to the two simultaneous messages and stop transmitting. Each station will then attempt to retransmit its message as some later time. This is the solution used by Ethernet
- CSMA-CA (Collision Analysis). Using this technique, the station transmitting the message with the lowest priority level stops, thus allowing the higher-priority level message continue. Management of priorities is based the coding of the frames transmitted. This is the solution used by BatiBus (see **fig. 14**).

□ Non-deterministic response times. Depending on the information load on the bus, the transmission time for a frame is not constant. It is therefore not possible to guarantee a maximum transmission time using a protocol implementing this type of access to the bus. However, a certain number of devices and design rules make it possible to ensure maximum transmission times that are nearly 100% certain. For example, in the BatiBus system, commands are priority messages. This is a means to avoid the response-time constraint.

□ Detection of faulty stations.
In a system using the master/slave method of access to the bus, the breakdown of a slave is detected by the master during the next polling cycle. But for protocols in which messages are transmitted only when necessary, a faulty module is not detected. Each application must therefore develop and implement the necessary monitoring devices required to periodically check the status of each module.

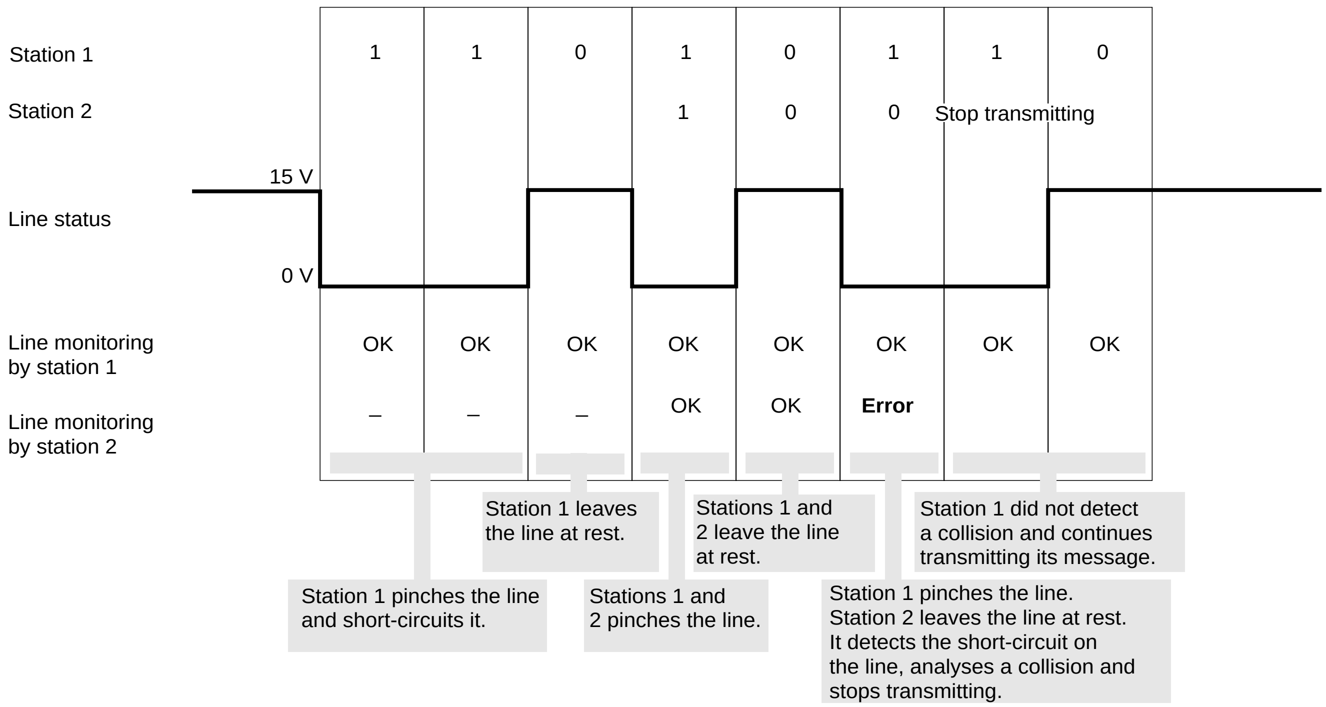


***fig. 14**: collision analysis in the BatiBus system.*

■ Advantages of a CSMA bus for an electrical installation
In the preceding paragraphs, it was shown how the constraints specific to CSMA buses may be avoided.
The main advantages that may be gained from this type of bus are listed below:

□ Optimised data exchange: a CSMA protocol optimises data exchange because the bus is not clogged with continuous polling operations. Consequently, for a stable application, which is generally the case for an electrical installation, with the same transmission speeds as a master/ slave protocol, the quantity of useful information transmitted is significantly increased and response times can even be shorter.

□ Reduced costs: the greater the transmission speed on the bus, the greater the system constraints concerning protection against electromagnetic disturbances and, consequently, the greater the costs. A CSMA protocol makes it possible to select slower transmission speeds and thus reduce transmission-related costs.

□ Decentralised processing: a protocol offering this type of access to the bus makes for optimised processing of decentralised and/or distributed operations. The example in **figure 15** (decentralisation) shows how data exchange can be simplified (opening orders to non-priority circuits) with respect to a centralised master/ slave system.
Note that for distributed processing, it is the measurement module which directly transmits the opening order to the non-priority loads. Consequently, even if the switchboard central unit has failed, load shedding remains possible.

Using FIP for MCC applications

Certain industrial applications impose very severe demands in terms of continuity of service and performance levels. For example, a guaranteed response time (deterministic) may be required for an order issued by an automatic-control function managing the industrial process. This is the case for certain MCC (Motor Control Centre) switchboards. Contrary to a main LV switchboard, opening and closing orders for devices are by no means exceptional.
In this case, the performance levels offered by buses implementing master/slave protocols are not sufficient, unless very high transmission speeds are used, with the corresponding high costs. Buses implementing random-access protocols are not up to the job either.

It was for this type of application that the FIP bus was designed by industrial companies and manufacturers. It is not within the scope of this document to present the FIP bus in detail, however, it should be noted that it combines the advantages of both master/slave and random-access protocols:
■ access to the bus is controlled by a bus manager located in the switchboard central unit (LV switchboards),

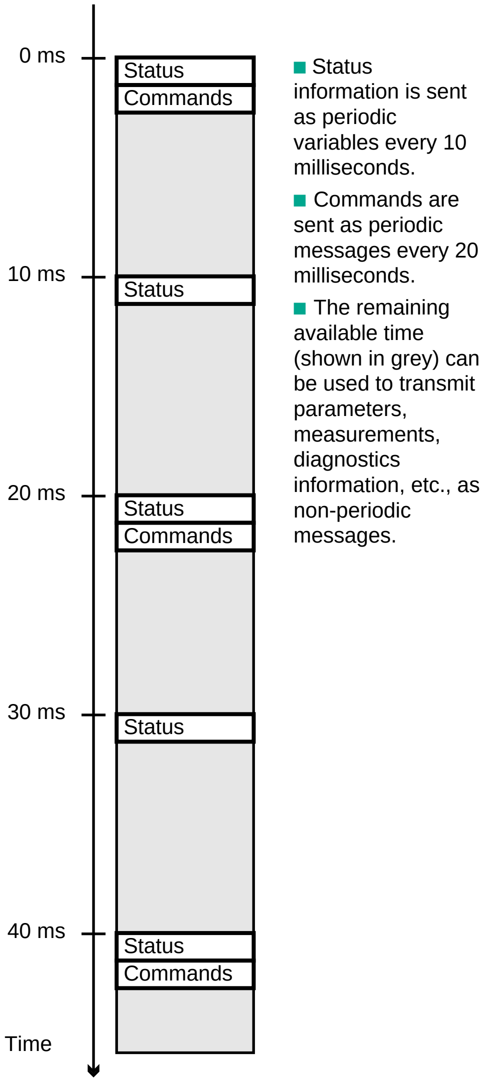


fig. 15: time diagram for an MCC implementing FIP.

■ data may be periodically transmitted over the bus (orders and status information, for example),
■ stations may request permission from the bus manager to transmit information, as needed, for example, in the event of a significant change in the value of a measurement, etc,
■ the data issued by one station may be used by one or several other stations, for example, for distributed processing,
■ finally, the protocol has a number of built-in systems that make it possible to guarantee a very high level of transmission dependability.

The FIP bus thus combines the advantages of:
■ master/slave protocols (deterministic and guaranteed response time),
■ random-access protocols (transmission of useful information or following an event).
The FIP bus offers a high level of performance and meets very severe dependability constraints.

4 Implementation examples

4.1 Computer centre

Needs

In a computer centre operating 24 hours per day, the primary concern of the electrical manager is to ensure continuous availability of power and fast response when maintenance is required.

In addition to these basic needs, the customer may want to reduce his energy bill by:

- improving the power factor;
- taking advantage of special tariffs with the utility, for example by agreeing to sharply reduce consumption on peak-demand days upon reception of a special signal.

Through these two modifications, the return on investment for the installation drops to less than three years due to the sharp decrease in electricity bills.

Implemented solution

- Electrical installation

The electrical installation is supplied by a 20 kV medium-voltage loop. The MV loop supplies a 1 000 kVA transformer which in turn supplies a main LV switchboard (see **fig. 16**).

The main LV switchboard is made up of

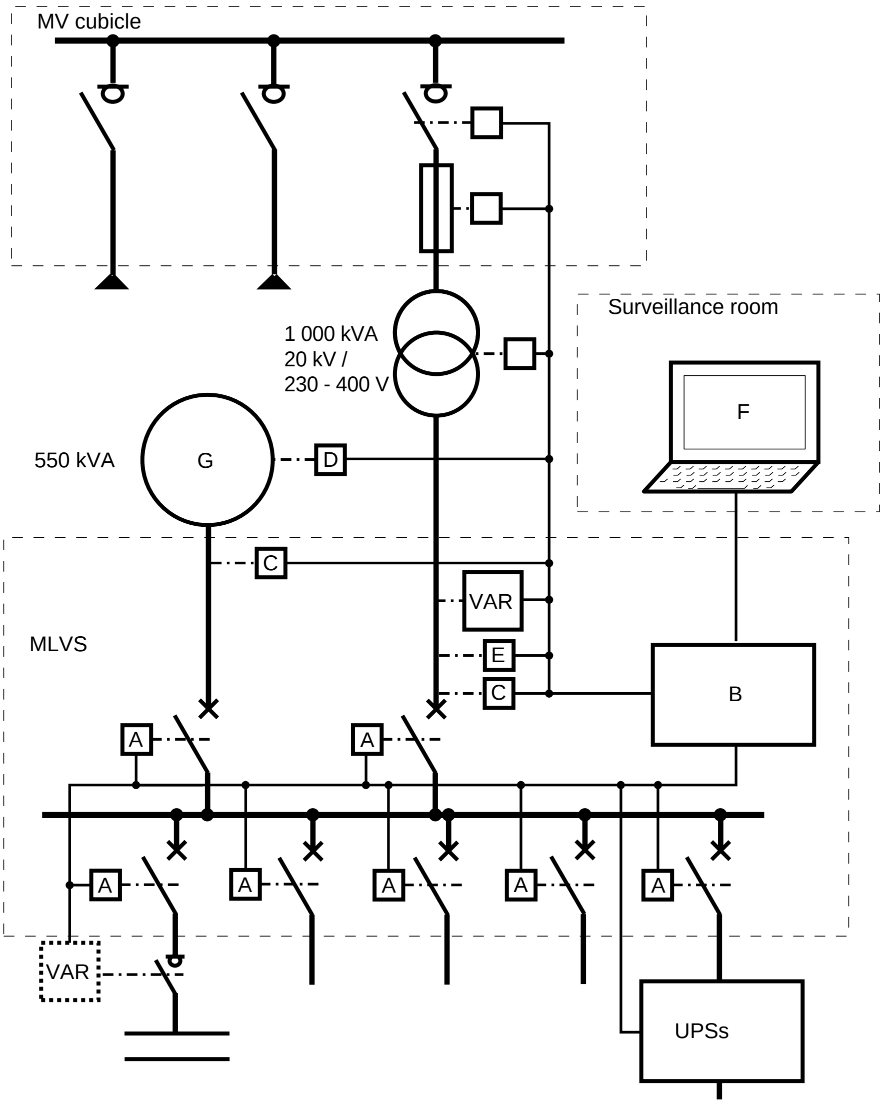


fig. 16: solution implemented for a computer centre.

withdrawable units. It supplies 23 outgoers, including two reserve outgoers. The high-power outgoers are equipped with motor mechanisms for remote-control purposes. The computers are protected by two UPSs set up in a redundant configuration. A 550 kVA engine-generator set can replace the power supply for all the electrical equipment in the computer centre.

■ Required functions

□ Source changeover. In the event of a voltage loss downstream of the MV/LV transformer (or if a load reduction signal is received from the utility), the switchboard is automatically supplied by the replacement source. The cabinet managing the engine-generator set receives the shutdown and start orders from the main LV switchboard and autonomously manages the engine-generator set.
When the load is transferred to the engine-generator set, the high-power outgoers are shed to reduce the load step change during switching, and are then reconnected one after the other according to an adjustable individual time delay.
When utility power returns (or the special utility signal is discontinued), the switchboard automatically transfers the load back to the normal source and requests shutdown of the engine-generator set.

□ Contract management. For special tariff contracts, the power utility sends a load reduction signal to the customer 30 minutes before actually shifting to the special mode. The signal, transmitted via the field bus, is decoded by a specific relay. On reception of the signal, the switchboard transfers the load to the engine-generator set, exactly as if a power failure had occurred. When the signal is discontinued, the load is automatically transferred back.

□ Reactive power regulation. A 100 kVAR capacitor bank used to compensate for reactive energy consumption is managed by a reactive power regulator.

□ Remote surveillance. In the event of an incident in the electrical installation, the watchperson is immediately informed via a supervision console which transmits any alarms issued by the main LV switchboard.

■ The control and monitoring system

□ Each incomer and outgoer in the main LV switchboard is managed by a module (marked A in the diagram), which:
- acquires the position of the device (open, closed, tripped, withdrawn, etc.);
- displays this status locally;
- for the remote-controlled incomers and outgoers, orders opening, closing or resetting. These orders may be given locally or sent via the switchboard bus;
- dialogues with the switchboard central unit via the digital communications bus.

□ The switchboard control unit (marked B in the diagram) located inside the main LV switchboard is in charge of:
- managing the control and monitoring functions for the incomers and outgoers via the modules marked A in the diagram;
- directly acquiring two elements of information, namely the presence of utility voltage or engine-generator set voltage (via voltage relays marked C in the diagram), and passage to the special utility mode (special utility relay marked E in the diagram);
- transmitting a start order to the cabinet (marked D in the diagram) managing the engine-generator set;
- processing the source changeovers caused by a failure in utility power or reception of the special utility signal;
- generating and transmitting any alarms to the supervision console (marked F in the diagram) which then displays them in the appropriate manner.

4.2 Hospital

Needs

In a hospital, the continuity of electrical power service is critical. The example below deals with a mid-sized hospital.

To provide optimum management of the electrical distribution system and in compliance with the expressed wishes of the operator:
■ Outgoers are divided into three categories, «backed-up» (by a generator set), «priority» (protected by a UPS) and «no-break» (protected by a UPS and a generator set). Each incomer and outgoer is monitored and may be remotely controlled from the supervisor;
■ The entire installation is remotely supervised.

Implemented solution

■ Electrical installation

□ The electrical installation is supplied by a 20 kV medium-voltage loop. The MV loop supplies three 1 000 kVA transformers which in turn supply an LV distribution switchboard.

□ Two 400 kVA engine-generator sets can step in to provide back-up power to certain electrical equipment in the hospital.

□ Two UPSs supply the no-break and priority outgoers.

□ The outgoers are grouped in three LV switch-boards. The diagram in **figure 17** makes clear the supply system for each outgoer in LV switchboard 1.

■ Organisation of power management

□ A supervision station (supervisor) may be used by the operator to monitor the installation, issue orders and set parameters.

□ The switchboard central unit in the LV distribution switchboard:
- provides control and monitoring of the circuit breakers on incomers and outgoers;
- checks operation of the reactive power relays (reactive-energy compensation) and stops compensation if utility voltage is absent (operation on the engine-generator sets);
- dialogues with the UPS processing units;
- supplies the «transformers ON» information.

□ The switchboard central unit in the engine-generator set LV switchboard:
- provides control and monitoring of the circuit breakers;
- dialogues with the control cabinets of the engine-generator sets for monitoring and transmission of ON and OFF orders;
- dialogues with the LV switchboards (1, 2, 3 and no-break) which issue a starting order for the engine-generator sets and receive a set-point indicating the maximum power available depending on the operating engine-generator sets and the LV switchboards supplied with power (all are not necessarily supplied during maintenance operations).

□ The central units in the LV switchboards 1, 2 and 3:
- control and monitor the circuit breakers;

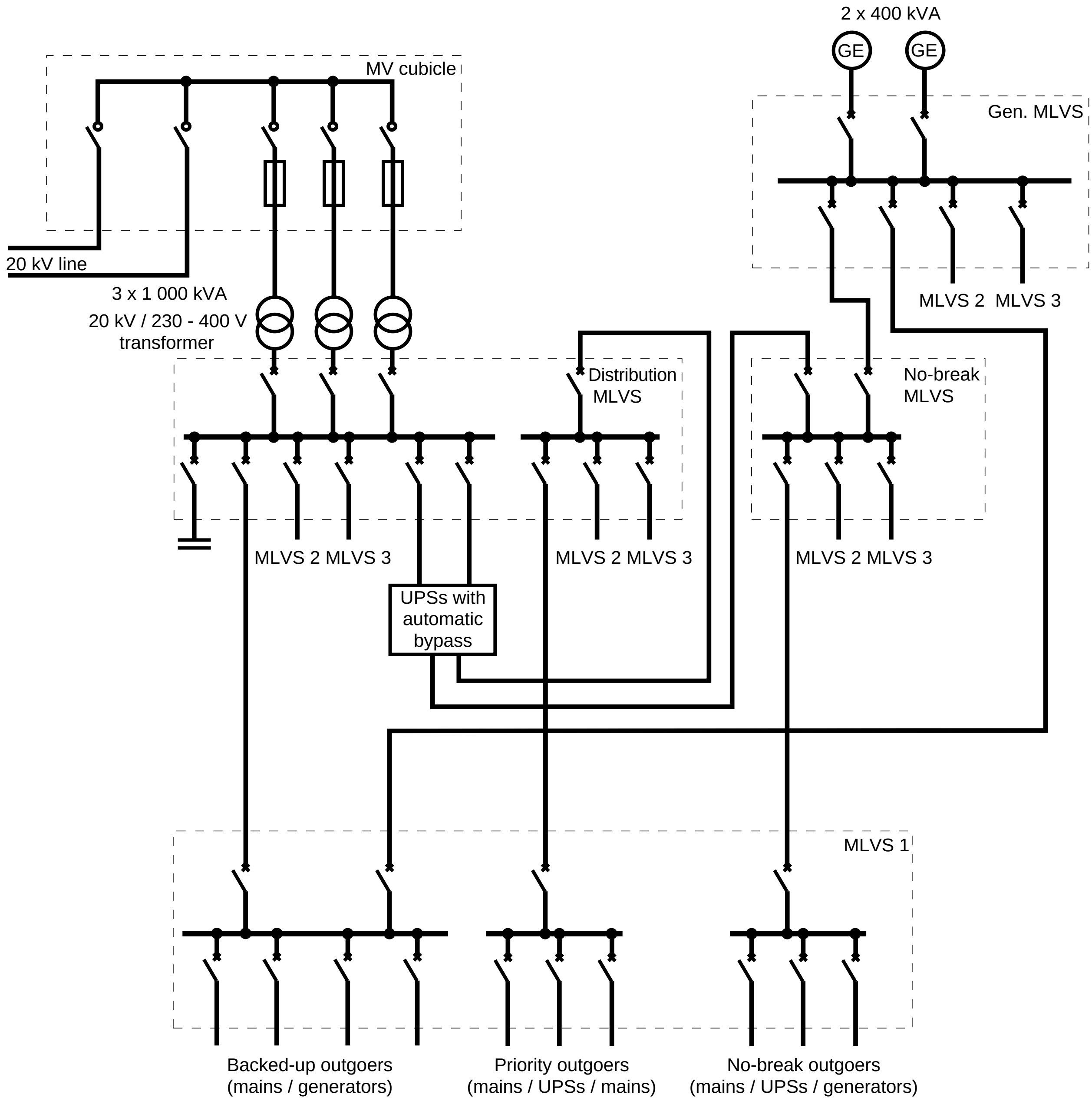


fig. 17: solution implemented for a hospital.

- provide the automatic source changeover function for the backed-up outgoers on the basis of the information supplied by the voltage relays, i.e.:
. load shedding of the major outgoers;
. transmission of a start request for the engine-generator sets;
. closing of the engine-generator set incoming circuit breaker;
- provide load regulation. Depending on the priority rating of the backed-up outgoers, they are shed and reconnected according to the power supplied by one or both engine-generator sets or by the transformers (1 and/or 2 and/or 3);
- dialogue with the insulation monitor for the «no-break» outgoers.

□ The central unit in the no-break LV switchboard:
- controls and monitors the circuit breakers;
- controls source changeovers, after requesting starting of an engine-generator set if the UPS signals a problem.

In this example, not all the available power-management functions are implemented (they never are).

■ Time management is not implemented because a hospital operates 24 hours per day.

■ Contract management (smoothing of peaks, special utility modes) was not applicable, only reactive-energy compensation was implemented.

■ The power-management system set up is entirely dedicated to ensuring maximum availability of electrical power.

■ Each switchboard received local and autonomous processing capacity to carry out its assigned functions.

■ Very little event information circulates on the bus (automatic source changeover, engine-generator sets, load regulation) and no measurement values except for metering values in the MV switchboard.
Status checks are run periodically.

5 Conclusion and prospects for the future

Intelligent switchboards, a critical element in electrical distribution systems, provide solutions meeting the needs of managers and operators of electrical installations, notably:

- energy savings;
- dependability;
- remote control of the installation (with possible extensions to building management for commercial applications and process management in industry);
- installation maintainability and upgradeability;
- gradual evolution of the installation over time toward greater intelligence.

The construction of switchboards with integrated management functions, but with decentralised and distributed intelligence, is today made much easier due to the existence of standardised modules, equipment and software that will remain available over long periods. In this sense, control and monitoring can now be implemented using concepts similar to those of type-tested assemblies and shows sharp differences with respect to automatic-control functions for industrial processes.

Integration of intelligence in switchboards has made it possible to:

- simplify switchboard and electrical-installation architecture, during the initial design process and later during upgrades (distributed electrical distribution, elimination of half busbar arrangements, discrimination, knowledge of switchboard reserves, management of operating conditions at switchboard maximum limits (temperature, overloads, etc.)):
- manage the switchboard over time (black-box function, up-to-date diagram file, etc.);
- combine communications functions (low currents) with power functions (high currents).

In the near future, communication and processing will continue even further downstream to the individual devices, sensors and actuators. This will make the distribution of intelligence easier and thus further reduce centralisation. Considerable advances may be expected in the fields of design, wiring, installation, operation, dependability and upgradeability.

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