DA concept for higher-quality power supplies

Low power network losses and an uninterrupted supply of electricity are no longer enough to satisfy today's consumers, who take a high-quality power supply for granted and also expect power generation, transmission and distribution to be environmentally friendly. Besides addressing these issues, electric power utilities have to take account of trends at the users' end when planning their operations. The DA, or Distribution Automation, concept was developed to help utilities meet these requirements.

The opening of the world's markets is intensifying the need to be competitive. In the new business environment, success will depend to a large extent on the priority given to customer satisfaction and to compliance with environmental legislation. Electric power utilities have to operate within this framework just like other branches of industry.

More efficient operation of the distribution networks is needed

Utilities have to adapt to the changing circumstances as well as to the new requirements of industry and other end-users. Major modifications to grids, involving upgrading of the larger transformers and the substations, are bringing about changes which are not restricted to power transmission and distribution but concern the utilities, too. For the power companies, deregulation is heralding a period of across-the-board transition.

Changes to a power system may, however, endanger the network's stability by increasing the risk of disturbance. Often, the only way to detect such a shortcoming is to carry out a network analysis. Afterwards, appropriate measures have to be found and implemented. There are two basic ways of going about this:

- Replacing the entire network with a new one which can handle the anticipated operating and short-circuit conditions.
- Upgrading the existing network through improved control and protection systems to make it satisfy the new requirements.

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A comparison of the cost of these two methods reveals some interesting figures: replacing just 1 km of 24-kV overhead line for the purpose of raising the power transmission level costs as much as replacing the protection equipment for the whole line. If, for example, an overhead line 100 to 200 km in length has to be replaced because of a change in the operating requirements (not due to a change in load), it makes more sense to improve just the level of automation in the distribution network.

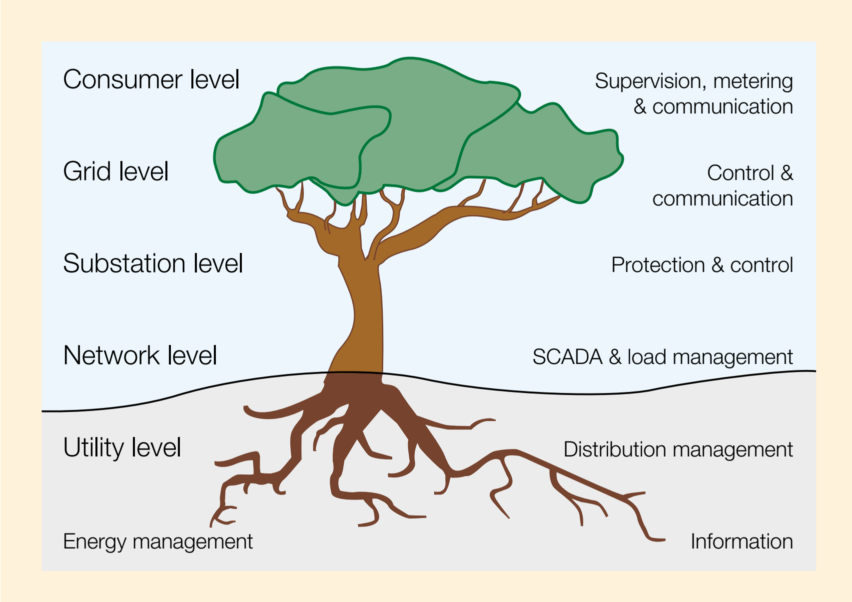
The deregulation that is sweeping the electric energy sector is sure to influence how distribution networks are utilized and also generate additional requirements that will have to be met by the utilities. To address these two issues, operators will have to have access to a wide range of information (eg, active and reactive power, and the status of the network). A high level of automation in the network is a precondition for collecting and evaluating such information.

It is already taken for granted that the quality of the electricity supply will be high. However, because of the increase in non-linear loads connected to the network, it is becoming more and more difficult to maintain a high standard. Primarily, these problems involve voltage and frequency fluctuation, and the elimination of transients and other disturbances. Also, there is an increasing need to address the question of financing.

What resources and what purchases will be needed to cover the present electricity demand? The answer will be driven by economic aspects, with the most favourably priced power production method and equipment available having to be used to generate and distribute the electrical energy. An optimization, however, presumes the availability of enough information about the power reserves, purchase options and market prices.

Integration into a total system

The DA (Distribution Automation) concept provides automatic adaptation of the distribution network to the requirements discussed above. It comprises several systems, integrated to provide a total system for operations control, energy and load management, plus distribution management, and allowing energy demand to always be met in the most cost-effective way. The DA concept fulfils all operational needs, from those of the the utility to those of the end-user **1**.



DA concept for network adaptation through automation at all electricity supply levels – from the power generation plant to the end-user **1**

Options for evaluating the DA concept

There are two different methods for evaluating the benefits of the DA concept:

- The *function family tree* (FFT) method, which provides a general assessment of the benefits.
- The *case research method,* in which the benefits gained from using the DA concept are assessed for a specific utility.

The FFT method allows a complex entity to be divided into successively smaller parts and involves several steps [1]. An extract from an FFT for a Finnish utility is shown in **2**.

The DA concept is especially useful for the support it offers in the areas of operational control, energy distribution, optimization of energy utilization and network design.

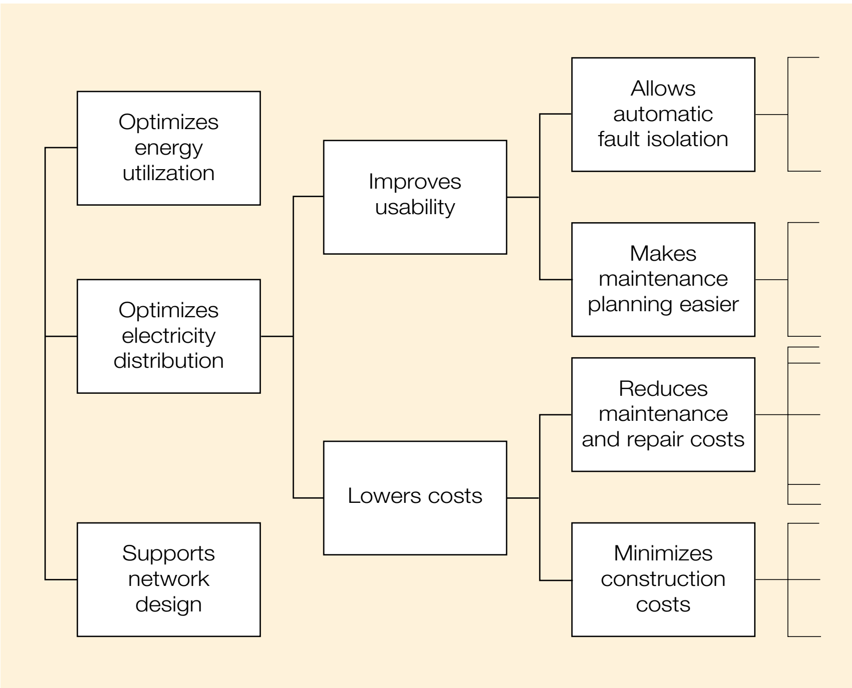
Ways of reducing the cost of distribution management systems

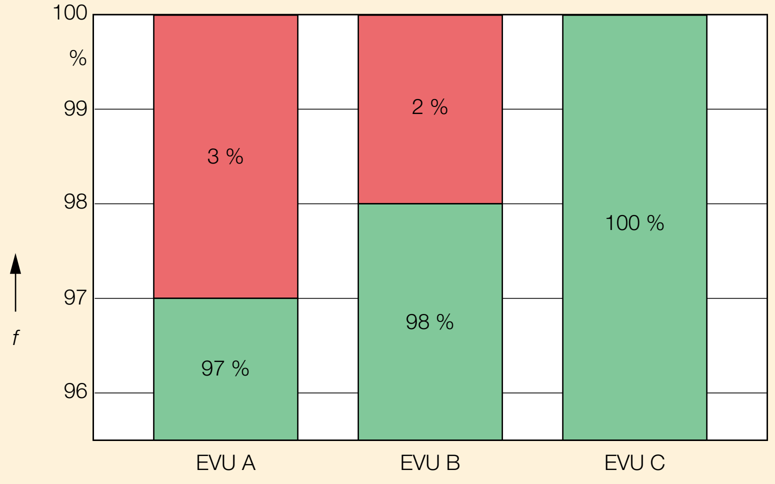
It is essential for a distribution management system (DMS) to be economical and user-friendly. Economy in this context means minimizing both the construction costs and the cost of maintenance. The latter is achieved through preventive maintenance and well-timed repairs. User-friendliness depends in the first place on how the maintenance is planned and on the self-monitoring and diagnostics facilities that are available.

Saving on system costs

The largest saving here is achieved through integration of the protection and data acquisition system. This simplifies the equipment configuration

Section of a tree pattern used to evaluate the areas of use of the DA concept in an electrical power network **2**





Failure rate f of distribution transformers of three different electric utilities (A, B and C) during the same thunderstorm.
The protection equipment of utilities A and B feature traditionally long tripping times, that of C short tripping times. **3**

Green *Intact* Red *Damaged*

and the secondary systems, thereby reducing the risk of faults and the need for maintenance. Reliability is improved as a result. By additionally integrating the load management system (LMS) into the network control system, one of the two control stations can be omitted. This translates into a saving for a medium-size utility of more than US$ 65,000. A further saving is possible by using a common operating system, as this will reduce the need for staff training and system maintenance.

Saving on repair and maintenance costs

The biggest saving in the area of repairs and maintenance is gained by using microprocessor-based relay protection, which can also have a positive effect on network operation in general. The main advantages of this kind of relay protection is that it is programmable and allows very fast response. Due to the faster response, tripping takes place in a shorter time and the tripping steps are smaller. This has several advantages:

- Lower thermal loading of the cables improves short-circuit behaviour without reducing selectivity.
- Damage to cables (especially those made of aluminium) due to short circuits is reduced.
- Network earth connections are minimized.
- Fewer faults involving the distribution transformers **3**.

The number of distribution transformer faults, which is also reduced by installing modern, high-performance surge arresters, is not only lower; the character of the faults has also changed. Whereas in the past distribution transformer faults occurring during thunderstorms were caused by surges due to lightning strikes some distance away, transformer damage these days is due almost entirely to direct strikes.

Programmable relays allow several tripping steps to be used, thus eliminating unnecessary trips while ensuring high-speed tripping when it is genuinely needed. This also improves the network protection selectivity. Unnecessary reclosure in the event of faults can be prevented by changing the parameters, thereby reducing the loading of the network and consumers' installations.

The protection system also includes self-monitoring functions and diagnostics that allow longer intervals between conventional relay testing than were previously possible.

Operations support software can be used to calculate and simulate a range of factors. Examples are the voltage drop (eg, for rural networks) and load capacity (for urban networks). Simulation can help in the location of weak points in a network and prevent unnecessary power supply interruptions.

The integration of different subsystems and the centralized management create redundant functionality, thus increasing the system's reliability and providing further opportunities for preventive maintenance.

Faster localization of network faults

The control room can quickly isolate a faulty section of the network by means of remote-controlled disconnector stations. In the worst case, when no personnel are on duty, the time needed to localize a fault is between 5 and 30 minutes.

Automatic fault localization and autoreclosure are used to clear faults. In remote-controlled disconnector stations, a faulty line is isolated from the network by the local automation equipment, based on decision functions incorporated in the protection equipment, within about 4 minutes. The automation offers utilities the following benefits:

- Reduction in labour (less time and fewer people are needed to localize faults).
- Reduced primary equipment wear (providing a cost-saving in the long term).
- Autoreclosure

The advantages for the customer are improved quality for the supply system, with fewer interruptions and shorter power outages.

Daily maintenance planning

Not all power supply interruptions are due to faults in the network. Some of them are the result of equipment failure or wear, and could be prevented with the help of a repairs and maintenance programme. Remote-controlled substations are also helpful in this area, as they allow a ring-type network or a temporary supply configuration, etc, to be established from the central control room 4.

Energy management

Distribution energy management (DEM) coordinates and safeguards the interests of the utilities, customers and the general public. A power utility's aim is to buy the electricity it currently requires at the lowest possible price and in the easiest possible way. This means optimizing the utilization of the alternative energy sources. The customer's primary concern is a reliable and high-quality power supply at an attractive price, but there is also a wider concern – ecological impact – which requires the potential effect of power generation and distribution decisions on the environment to also be taken into account.

Data exchange and optimization of the energy balance

As the electricity market deregulates (eg, within the European Union), the likely trend is that distribution utilities will purchase from several power suppliers through both long- and short-term contracts. Another possibility is that an 'electricity stock exchange' will be established for short-term trading.

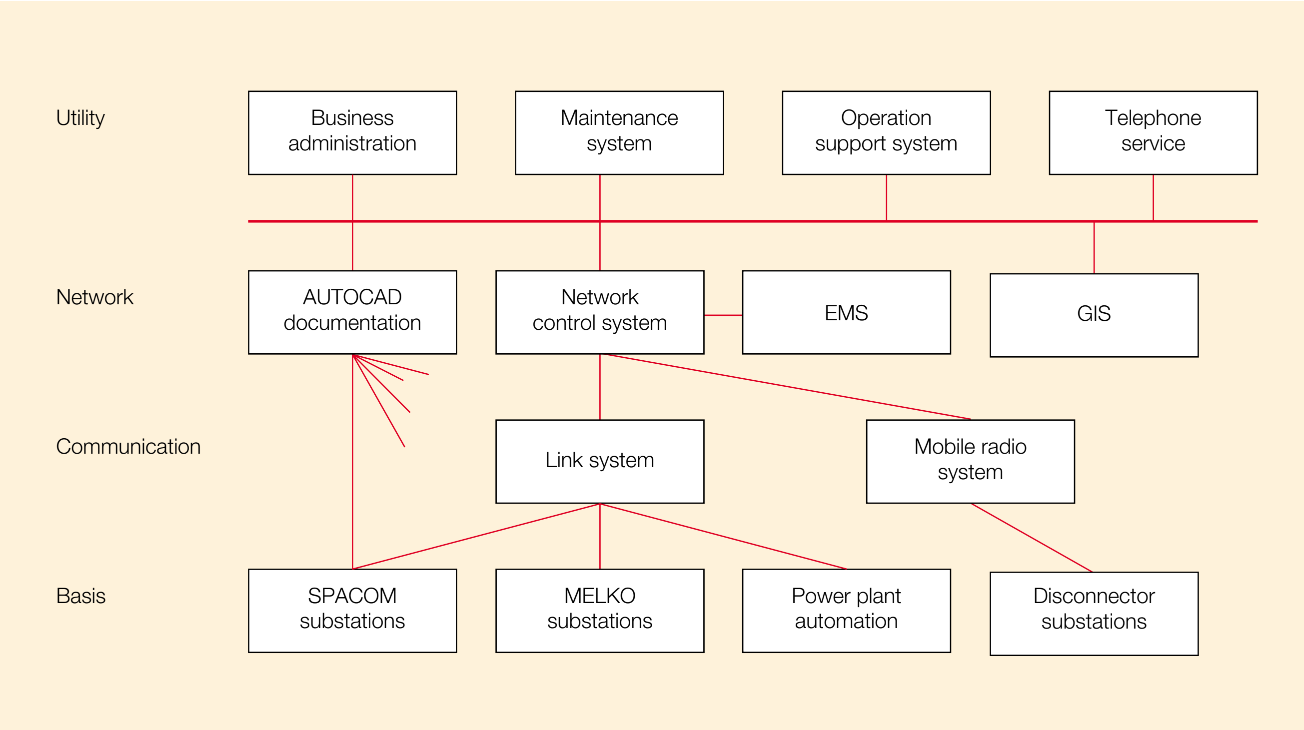
The DEM system supports these activities, which require, in practice, centralized control of all items related to power supply. To these belong the different operations documents (eg, logs of the active and reactive power), preparation and use of load forecasts, and monitoring of the purchased power and of the control, automation and alarm equipment. The DA concept provides for their implementation through a SCADA system.

In principle, two possibilities exist for achieving an energy balance:

- A simpler system, created using application tools and starting from measurements at the substation level.
- A more comprehensive and independent system that communicates with the SCADA system via an interface.

The preferred method will depend on the user's requirements and the specific needs of the application. The simpler method will be sufficient if the production process can be ignored. The inclusion of the production process (eg, in

The DA concept for automated network adaptation supports maintenance work through fault localization and power system changeover from the central control room. 4



Implementation of the DA concept at a Finnish electric utility (case study) **5**

the case of power wholesale supplies) will make an optimization more necessary, in which case the more comprehensive system is to be preferred. An optimized energy balance can reduce the power transmission losses and, by avoiding energy wastage, lessen the impact on the environment.

Information systems for staff and customers

Every time a fault occurs, pressure is exerted on the operating staff from two sides: on the one hand, they should establish the cause of the fault and initiate appropriate remedial measures as fast as possible; on the other, they have to inform the customers of the origin and duration of the disturbance as quickly as possible. The customer information system is a focal point of current DA development work. Through further development of the real-time interface between the public telephone network and the electricity network control system, it should soon be possible to replace the present manual information system by an automated one. With such a system in place, customers will be able to access real-time information even during normal network operation, for example to inform themselves about possible country-wide faults or rationing of the electricity. Automation will mean that the operating staff are no longer responsible for informing customers, allowing them to concentrate instead on localizing and isolating the fault, then eliminating it and restoring the network to its normal condition.

When the DA concept is implemented, the control system also knows the exact time the fault occurred and when it was eliminated, allowing the duration of the interruption for the end-user to be easily calculated. Through transmission of this information to the Customer Data System (CDS) and combining it with area data already stored, the duration of the interruption can be calculated and reported to each individual key customer. In the future, the CDS will also include additional service information, such as notices of change of address and on-line billing information. This will enable forward-looking utilities to give customers even better service.

Network design

The DA concept allows the databases of network design programs and distribution management systems to be combined. Thus, the network data only need to be stored in one database, saving both time and money. In addition, it helps to avoid the problems that can be caused when different database versions are installed.

Case study involving a Finnish utility

The Finnish utility in question is located in a rural area and implemented the DA concept shown in **5** in 1990. The area served by the utility is large in comparison with sales, and covers terrain in which hills and lakes dominate. The high-voltage lines run mainly through forests **6**.

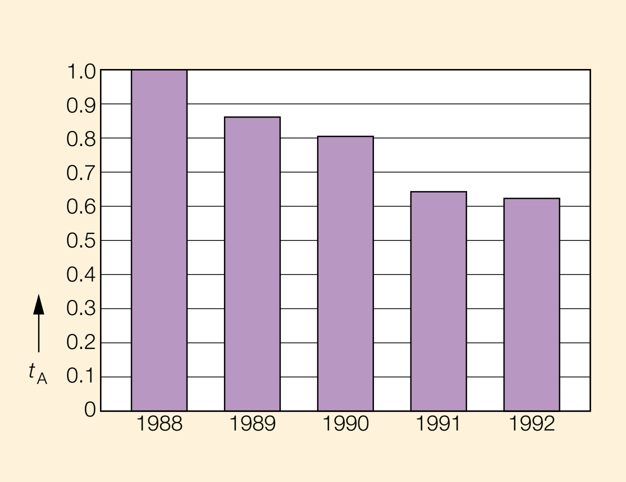
Thanks to the DA concept, the utility has been able to significantly reduce necessary investment in the network, allowing pay-back of the system's costs in just five years.

Besides the saving in construction costs, which was mainly due to the integration of the dispatching center, the use of two-stage earth fault protection enabled the utility to reduce expenditures for the earthing system. The first step responds at a low earth current of 1 to 2 A after a delay time of 1.3 to 1.5 s. This eliminates spurious tripping. The second step responds after just 0.35 s, when the value of an earth-fault current (8–10 A) causes the zero voltage to rise significantly. Use of this protection results in a saving in copper as well as labour costs for the earthing, especially in areas where dry moorland predominates.

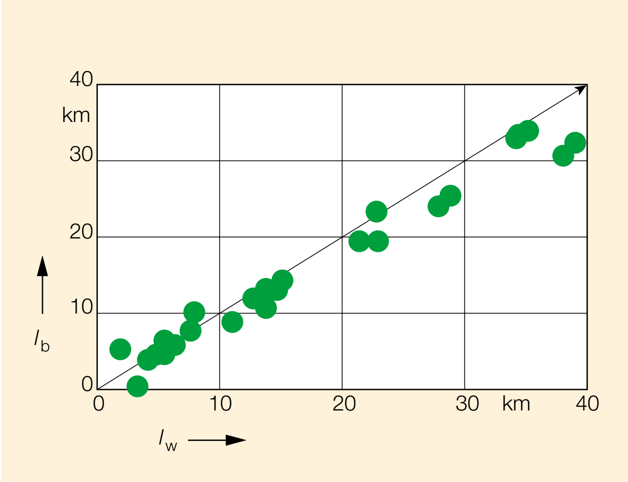
The most substantial saving in the repairs and maintenance area is achieved through the automation of the disconnector substation. Automatic control allows the maintenance crew to proceed systematically, without having to first localize a fault by means of preparatory switching operations. The DA concept also helps to reduce the amount of equipment needed. For example, whereas an average of ten distribution transformers were damaged every summer in the past by thunderstorms, this figure could be lowered to an average of just one.

The introduction of the DA concept allowed the utility to reduce the staff and number of vehicles used for localizing faults. Now, with the DA concept implemented, only one combined fault localizing and repair group is required per fault instead of the 2 to 4 groups per fault needed in the past. Also, the fault localization time could be reduced from 1–3 hours to 3–60 minutes. For

Substation belonging to a Finnish electric utility serving a rural area (case study) **6**



Relative average outage times t_A between 1988 (= 1) and 1992, after introduction of the DA concept by a Finnish electric utility (case study). The cost of maintenance was also reduced over the same period. **7**



Short-circuit statistics of a Finnish electric utility considered for 1991 (case study, Table 1) **8**

l_b *Calculated distance to short-circuit fault*
l_w *Actual distance to short-circuit fault*

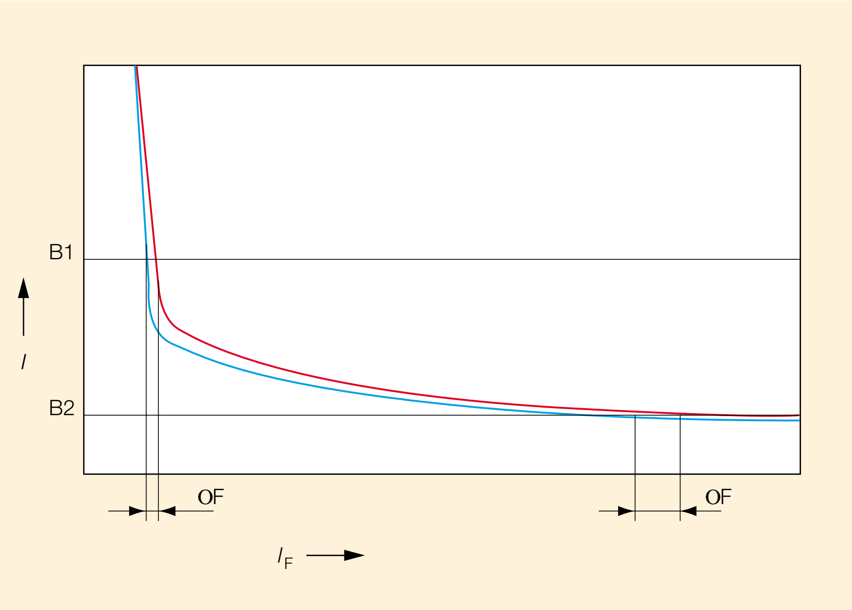
the end-user, this translates into shorter interruptions and a higher quality and reliability for the power supply **7**.

The effectiveness of the DA concept is also verified by the utility's short-circuit statistics for 1991 **8** (*Table 1*). Since that year, the situation has improved again, mainly because calculations now take greater account of the compensation of the load current. The accuracy of the calculations depends on how far from the station the short-circuit occurs. This is because the load current component of the short-circuit current increases by up to 10 percent as the distance increases **9**. Without this compensation, the calculations would show the fault to be closer to the station than it actually is. Thus, the calculation error is reduced to less than 500 m, a major improvement over the average error of 1.2 km that was usual earlier.

In the event of a fault, the utility's customers are served by an operations support system which informs them, via an answering machine that runs on a PC, about the station and bay involved, the actual repair status and the estimated outage time. The answering machine assembles an individual message based on the input data and can answer several lines simultaneously. As the repair proceeds, the duty personnel can modify the contents of the message using the menus (eg, the fault area, progress of repair work, estimated time, etc).

Load-current compensation: short-circuit current (red) and load current (blue) as a function of the distance to the fault l_F **9**

B1 *Example 1: small load-current component in short-circuit current, high calculation accuracy*
B2 *Example 2: large load-current component in short-circuit current (up to 10%), causing greater error in distance calculated by relay*
OF *Error in distance calculation*

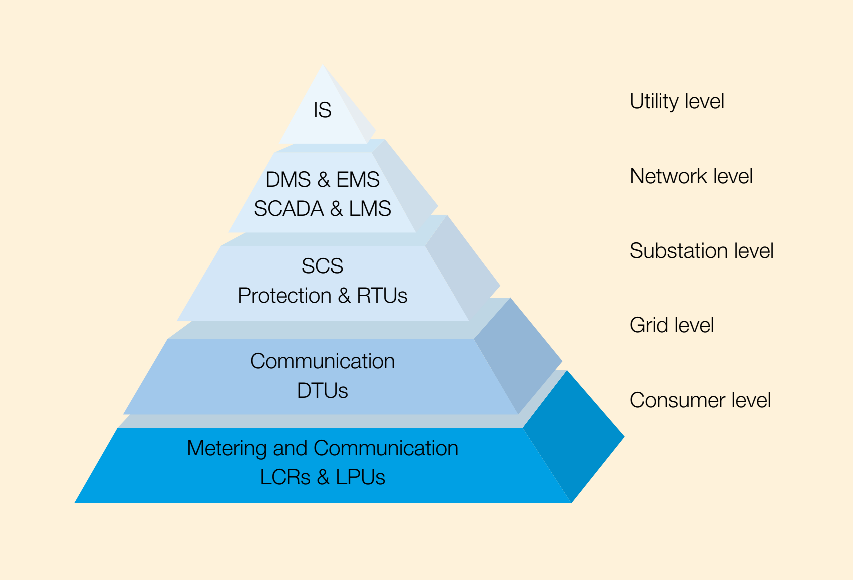


Automation has allowed a reduction of approximately 7 percent in the total number of personnel employed by the utility over the last five years. At the same time, the quality of the power supply has improved and there have been fewer power failures, the cost of which to the general public in terms of inconvenience and also to the economy at large should not be underestimated.

An investment that is quickly paid back

Research has verified that whenever the demands made on a network change it pays to carry out a network analysis before deciding on further action. In many cases, it is more profitable to increase the level of automation than to rebuild the network. The investment and operating costs will still be lower than the cost of a partial rebuild or the replacement of some of the cables.

The case study referred to confirms that the DA concept meets the general distribution management requirements of electric utilities. Total network planning according to the DA concept provides a complete overview of the network status and complete and rapid control of its operation from the control room at all times. Remote control of the individual substations and of subfunctions for integrated fault localization and short-circuit, overcurrent and earth-fault protection, all make operation easier. The cost-saving allowed by the DA concept is significant.



The DA concept for network adaptation through automation at all power supply levels **10**

IS *Information system*
DMS *Distribution management system*
EMS *Energy management system*
SCADA *Supervisory control and data acquisition*
LMS *Load management system*
SCS *Substation control system*
RTU *Remote terminal unit*
DTU *Disconnector terminal unit*
LCR *Load control receiver*
LPU *Load point unit*

ABB offers utilities a total DA concept implementation package that makes its integration in existing systems easier and speeds up the realisation of DA projects **10**.

Reference

[1] J. Marsh: The quality toolkit, an A–Z of tools and techniques. Information Press, Oxford 1993.

Table 1:
Short-circuit statistics of a Finnish electric utility.
39 faults were recorded in the year considered (1991).

		Most remote fault	Closest fault	Average distance to fault
Distance	km	38.9	2.0	14.1
Calculation error	km	5.9	0.0	1.2

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