DartNet® – the new PLC communications system for MV and LV networks

The DartNet® distribution line carrier system is a new PLC communications system designed especially for medium- and low-voltage distribution networks. Developed for two-way communication between substations and load sites, it has special advantages for remote meter reading, load management and distribution automation. DartNet meets the needs of a changing energy sector in which deregulation is stimulating strong interest in better utilization of the existing infrastructure and in optimizing supply network management. More efficient use of information systems, involving network-wide data acquisition and based on demand-side forces, will play a key role in this development. Advanced communications provides a platform for distribution automation, load management and automatic meter reading solutions by establishing reliable, economic links to thousands of terminal units, including those of end-users.

Recent years have seen the energy markets in the Anglo-Saxon and Nordic countries open up along a wide front, and remote control and telemonitoring of the distribution networks is becoming established in many areas. As new laws are passed, deregulation on a similar scale can be expected to take hold throughout central and southern Europe.

The use of advanced communications systems for the economic management of electrical networks is playing an increasingly important role in this new environment. Such systems have been used for many years to support the control of the high-voltage transmission network and are now also being installed in medium- and low-voltage networks **1**.

This branch of engineering, referred to generically as DA/DSM, for Distribution Automation and Demand Side Management, covers systems for automatic meter reading, load control and the automation of distribution networks, each with the aim of improving the cost/benefit ratio of the network.

It is a tempting thought when searching for a convenient communications system to use the power network as the carrier medium. Besides allowing every site in the network to be accessed directly, it has the advantage that the owner is also the user of the infrastructure. This reduces operating costs to an absolute minimum and gives the user full control of the system.

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Power line carrier (PLC) communication via overhead transmission lines is a well-established technology. ABB has a wealth of experience in this field, having introduced point-to-point communication over high-voltage lines some 50 years ago. In the meantime these systems have proved their worth in installations around the world.

A number of systems for remote meter reading (including 30 from ABB) have also been used for about 10 years in the much denser and highly meshed distribution networks at the medium-voltage and low-voltage levels. However, technical limitations, restricted data rates and relatively high costs have narrowed their application until now to automatic meter reading, usually involving special-tariff customers.

With the new technologies available today, particularly digital signal processing, much higher data rates are possible at lower prices and with improved robustness. This is widening the range of possible applications considerably **2**, and as a result the cost/benefit ratio has been improved dramatically.

Abbreviations and equipment designations used in this article

PLC	*Power line carrier*
DLC	*Distribution line carrier*
RTU	*Remote terminal unit*
DA/DSM	*Distribution automation and demand side management*
DLM 100	*DLC controller for medium voltage*
DLC 100	*DLC inductive coupler for medium voltage*
DLC 120	*DLC capacitive coupler for medium voltage*
INC 120	*Intelligent node controller (data concentrator)*
CMU 100	*Consumer management unit, controller for low-voltage meter readings*
DMU 100	*DLC for medium-voltage meter reading unit*

The DartNet DLC system

1 *Electricity meter*
2 *DLC-M communications controller*
3 *Inductive MV coupler*
4 *Packaged transformer substation*

Different PLC systems are available today for communication over:

- High-voltage transmission lines
- Meshed medium- and low-voltage distribution networks
- In-house low-voltage systems
- The so-called 'last mile', eg high-speed transmission for Internet and telephony services

Meshed networks make considerably higher demands on the protocols used since communication has to be guaranteed under constantly changing network conditions. Such systems are referred to as Distribution Line Carrier Systems (DLC).

Since a transmission line acts as an antenna the moment it leaves the ground, several rules have to be followed. For the first of the three application areas mentioned above there are standards and regulations which define the communication frequencies and power levels. The possible data rates are thus limited when these standardized restrictions apply; **3** shows the frequencies specified for them.

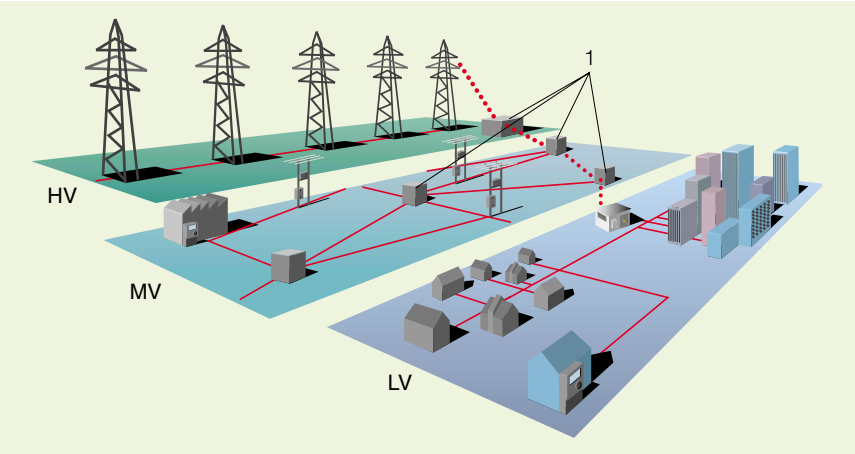
The fourth application area ('last mile' Internet and telephony) is being driven not by the energy market but by the deregulation of the telecom market, and attempts to break the monopoly on the single access to the home for such services.

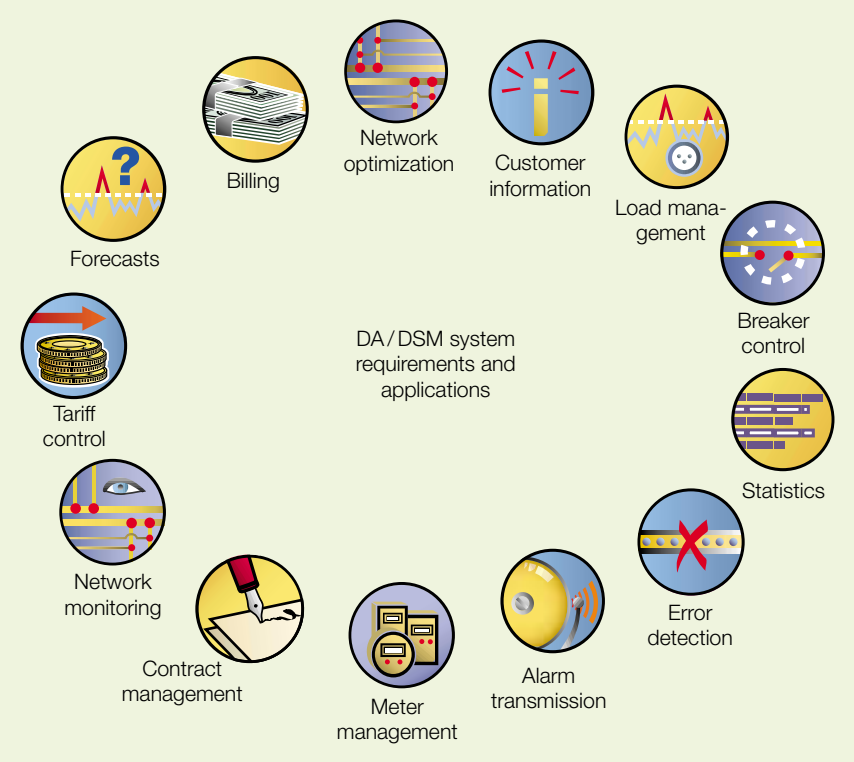
In Europe as many as 200 households share a low-voltage power line. This means that for several users to communicate over the same low-voltage line at the same time, data rates in the range of several Mbit/s would be necessary. However, the frequency ranges that would be needed for this lie within the bandwidths used for radio transmissions and military communications, so that approval to use them is not normally given. A number of European companies

Advanced communications systems are used today to oversee all the voltage levels of electrical power networks **1**

HV *High-voltage system*
MV *Medium-voltage system*
LV *Low-voltage system*

1 *Substations*





System requirements and application areas of a modern DA/DSM system 2

are currently trying to gain permission from the regulatory authorities to use some of these frequency bands.

The new DartNet DLC System

Supported by ABB Corporate Research in Switzerland and ABB Utility Automation in Germany, Swiss-based ABB Power Automation has developed DartNet as a highly advanced and powerful distribution line carrier (DLC) system for DA/DSM applications in MV and LV networks.

By making innovative use of new technologies in the areas of digital signal processing, coupling and protocols, ABB has brought to the market DartNet, a highly advanced power line carrier communications system for distribution networks which offers high transmission security and data rates that have been unattainable until now.

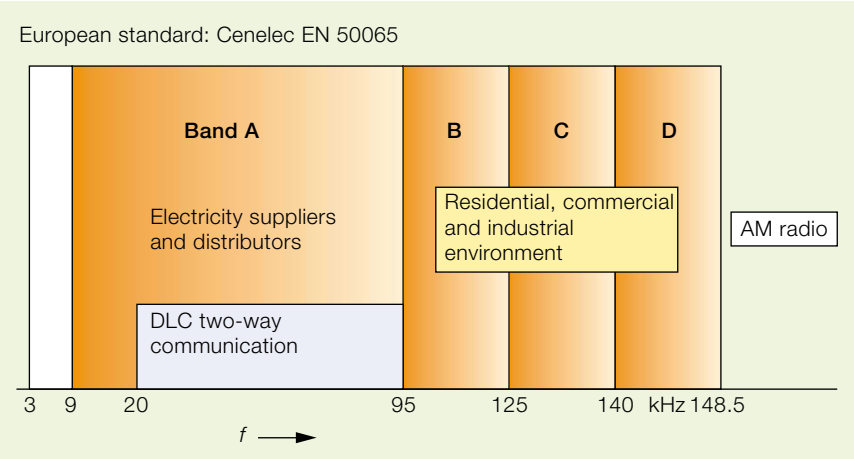
With DartNet DLC, ABB offers a communications system combining everything that is needed for distribution automation, load management and automatic meter reading, and at the same time fulfils all the pertinent standards and regulations (*Table 1*).

Features of the new DartNet DLC system 4 include:

- Two-way communication between substations and household meters
- Support for many different applications
- High data rates
- Real-time capability for distribution automation
- A powerful protocol for high transmission security
- Integrated network management with supporting functions, eg remote parameterization
- Compatibility with pertinent IEC and EN recommendations and regulations
- Standardized interfaces for connecting remote terminal units and meters
- New, cost-effective coupling methods

The principal DartNet DLC system components, which are designed to form a flexible, modular structure, are the network server, intelligent node controllers, a range of terminal units, and DLC communications controller.

Frequency ranges for PLC distribution networks as per EN 50065 3



Network server

The network server, designated INC200, manages the communications network and provides the interface to the control level. In addition to using the existing dedicated lines or fiber-optic links to communicate with the relevant units in the primary substation, it also supports a wide range of LAN and host computer protocols.

Its process database features interfaces to the relational databases and business

management systems that process the large quantities of data, especially the meter readings.

The server also provides the tools the maintenance staff need to configure and monitor the communications system.

Intelligent node controller

The node controller, INC 100, is a key component in the ABB concept for DA/DSM communications systems used for automatic meter reading and distribution network control, etc. In networks with thousands of terminal units, the INC100 allows innovative handling of the communications with the central communications computer.

The node controller, in effect a remote communications unit with its own intelligence, allows independent control of subordinate and local processes. Local preprocessing of the data reduces the total amount of data that has to be transmitted.

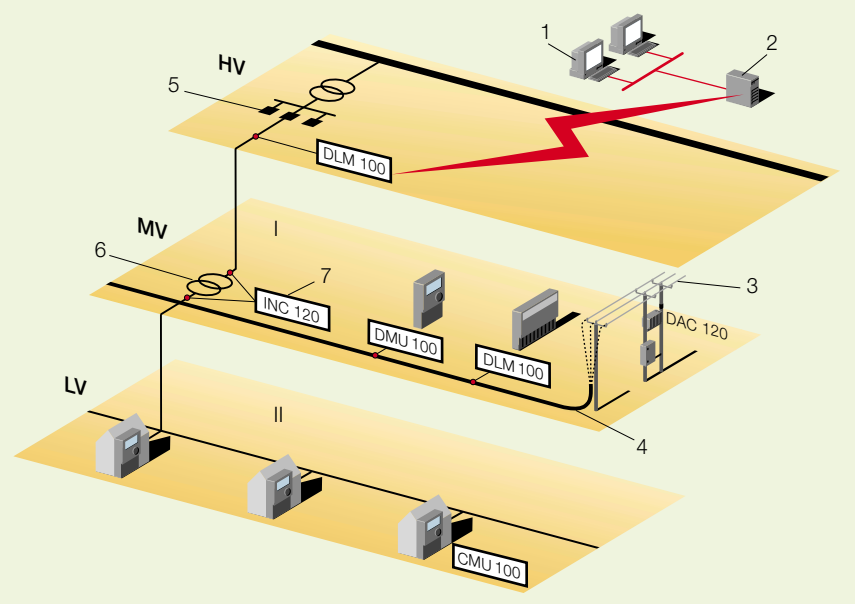
The node controller collects and records the data from all of the connected meters or RTUs within its section of the network, preprocessing the data before it delivers them to the higher-order computer. Command signals from the control center can also be transmitted to the meters.

Within the INC 100 series the INC 120 **5** is programmed as a data concentrator and is typically located in the substation, between the MV and the LV networks, thus forming a link between these two voltage levels.

The INC 100 offers a powerful and flexible platform and can be easily and quickly adapted to customers' requirements. The same controller can also be used to transmit data via a mobile radio or telephone network to the control center, and convert between a variety of data protocols.

Communications controllers

A range of intelligent communications units are available for connecting to RTUs as well as mechanical and electrical meters, alarm



DartNet DLC sytem architecture **4**

HV *High-voltage level*
MV *Medium-voltage level*
LV *Low-voltage level*

I *DLC-M two-way communication for automatic meter reading and distribution automation*
II *DLC-L two-way communication for automatic meter reading and load management*

1 *Host computer, control center*
2 *Network access server*
3 *Overhead line*
4 *Cable network*
5 *Primary substation*
6 *Secondary substation*
7 *Data concentrator*

DLM 100 *DLC-M communications controller*
INC 120 *Intelligent node controller (data concentrator)*
DMU 100 *DLC-M medium-voltage meter reading, special-tariff customers*
CMU 100 *DLC-L low-voltage meter reading and load management, households*

Table 1:
Technical data of the DartNet DLC system

Frequency range	20 to 95 kHz, as per EN50065 and IEC 61334-3-1
Modulation	– MV: multicarrier modulation with forward error-correcting and error-detecting codes – LV: Fast frequency hopping
Power output	– typ 1 W
Range	– MV: up to 10 km without repeater – LV: up to 1 km without repeater – Repeater functionality is included in every communications unit
Data rate	– MV: max 72 kbps, automatic adaptation to channel – LV: 1.2 kbps
Protocol	IEC 61334-based communications protocol, supports most telemetry, SCADA and automatic meter reading protocols. Both polling and event driven transmission are possible.

Data concentrator, INC 120 (1), in a substation with MV and LV DLC communications and connected RTU (2) **5**

Pole-mounted, gas-insulated switch remotely controlled by DLC communication **6**

equipment, etc. Typically, the units are prepackaged and factory-configured for easy installation in the field **6**. Special attention was given during development of the system to ensuring the high level of flexibility needed for trouble-free connection of units from different vendors.

Overview of DLC technology

Couplers provide the interfaces between the power lines and the communications system. Depending on the application and environment, either capacitive or inductive couplers will be used. It is also essential when designing a robust and reliable communications system to carefully consider the properties required of the transmission channel. The modulation technique then has to be selected, matching it as closely as possible with the transmission channel. Finally, a powerful protocol is needed to transmit the data between the stations and automatically repeat them in the event of a transmission error occurring.

Inductive and capacitive coupling

The coupling of the high-frequency signal onto the power line, which must be as cost-effective and reliable as possible, has a decisive influence on the technical properties and cost of the overall system. New coupling methods allow optimum solutions that also take into consideration the different boundary constraints **7**. Installation is easy and can be largely carried out by the customer himself.

With *inductive coupling* a special transformer is used to couple the signal onto the earth wire of the cable shield. The earth then acts as the return path. The coupler has been designed to withstand high short-circuit and earth-fault currents. Since the live phase is not utilized, installation can be completed in a very short time. This cost-effective solution is especially well suited for shielded medium-voltage cable, particularly in urban networks.

Capacitive coupling into a phase by means of a capacitor is a solution wherever there are no cable shields (eg, in the case of overhead lines) and where the shields are very old. A new, compact capacitive MV

coupler provides an excellent solution even where space is very limited. Capacitive coupling is used exclusively at the low-voltage level, the coupling being integrated directly in the power supply unit of the LV equipment.

The combination of these two methods is a special strength of the DartNet DLC system. Tests have confirmed that direct communication between inductive and capacitive couplers, and therefore between unshielded lines and shielded cables, is possible, doing away with the need for additional installations.

Power lines as transmission channels

Power distribution networks have several features which make them ideal as data transmission media. Nevertheless, the lines are designed primarily to transmit electrical energy rather than data. Because of this, a profound knowledge and understanding of the communications-related line properties is absolutely essential. ABB has gathered considerable experience from theoretical analyses and measurements carried out all over the world. The lessons learned can be summarized as follows:

- The properties of the transmission channel depend on a large number of factors that cannot be influenced, eg location, time, frequency and type of power line (overhead line, old cable, new cable, etc). A communications system therefore has to be robust enough to take account of all of these factors.
- Reflections or the connection of electrical loads can distort the received signal. The sensitivity of the transmission system to such distortion therefore has to be minimal.
- Electrical loads (eg, electric drives) can severely disturb communication by generating unwanted noise. Other frequent sources of disturbance are switching operations. A good communications system must operate reliably in spite of such disturbances.

A typical signal-to-noise characteristic for a transmission line is given in 8.

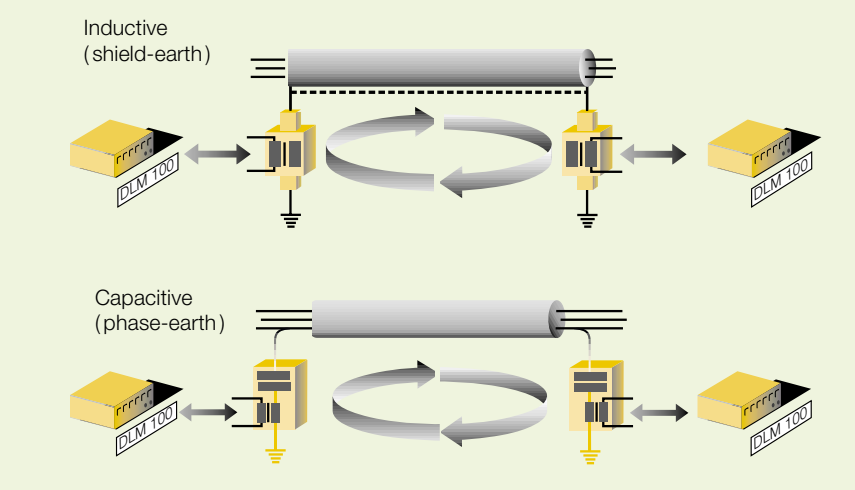
Modern modulation techniques

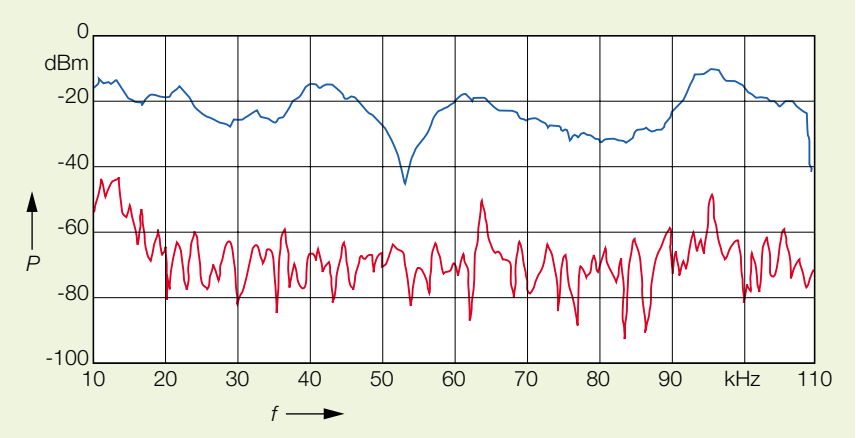
For long-distance transmission of a digital data stream (zeros and ones) to work at all, the stream has to be adapted to the channel by means of modulation. Traditional DLC systems use simple frequency shift keying (FSK) for this; in FSK modulation a logical '1' is assigned to one frequency and '0' to another. However, this simple technology allows only relatively low data rates due to the possibility of distortion in the transmission channel, and it is too susceptible to disturbance for highly sensitive applications. If just one frequency is disturbed, the link is interrupted as long as the disturbance is still present. In the DartNet DLC system new modulation methods are used which have been specially adapted to the properties of the transmission channel and the requirements of the applications.

For medium-voltage networks, in which data concentration and real-time requirements call for high data rates, a method called multicarrier modulation (MCM) is used, also known as the orthogonal frequency division multiplex (OFDM) or discrete multitone (DMT) method. This type of modulation unites the advantages of good bandwidth efficiency for high data rates with a flexible bandwidth allocation. The available frequency band is divided into different channels, each of which is modulated with a limited data rate. This lengthens the symbol duration, which, in spite of the high data rate, reduces the sensitivity to distortion in the transmission channel. Error correction methods can also be implemented to further improve the signal-to-noise ratio.

In low-voltage networks the higher level of attenuation and the numerous disturbances that occur have an even greater influence on the transmission quality than at the medium-voltage level; on the other hand, lower data rates are required. Fast frequency hopping, in which the information is converted into a sequence of time-limited signals transmitted at different frequencies, is therefore the most suitable type of modulation for this. The receiver is able to reconstruct the transmitted information even when massive channel distortion or 'loud' noise results in only one of the frequencies being correctly received.

Principle of inductive and capacitive coupling 7





Measurements covering an 8-km overhead line with several interposing transition points. The blue curve shows the transmitted signal (receiving end), and the red curve the noise on the line. The difference between the two curves is referred to as the signal-to-noise ratio. 8

f Frequency

P Signal and noise level in dBm

Robust transmission protocol

The development of a robust transmission protocol represented a major challenge. This protocol has to allow communication in a meshed network in which thousands of units have to be accessible at all times under not only difficult but also constantly changing conditions.

Conventional telemetry and SCADA protocols presuppose a largely undisturbed transmission channel, as for example in the case of a two-wire link. However, this is seldom the case with power line carrier transmission (and also, incidentally, radio transmission). The DLC protocol, which is based on the OSI Layer Model and the IEC 61334 standard, has the task of making a transmission channel available to a higher-order, application-specific protocol as dependably as if the units were connected to each other.

The protocol responds independently to constantly changing conditions in the distribution network, such as:

- Frequency-dependent disturbances originating in motors, phase controllers, etc
- Reflections received from open breakers, cable joints, etc
- High noise levels
- Pulsed disturbances
- Power system switching

The DartNet DLC protocol thus takes account of the problems in the distribution network and supports a wide range of existing protocols, eg IEC870-5-x, DNP3.0, WISP, etc. This allows it to be integrated in systems supplied by different vendors.

The DartNet DLC system is divided into hierarchical levels, referred to as 'domains'. Each communications module can be configured as a 'master' or 'slave'. Slaves can repeat messages. The master, acting in background mode, automatically checks the transmission quality and the accessibility of the units which have logged on within its domain. This 'accessibility table' is automatically re-transmitted to the next-higher domain. If a unit can no longer be reached, a new communications path is searched for immediately (and for the user invisibly) in order to re-route the transmission.

Features of the protocol include:

- Efficient packet data communication
- Automatic adaptation to channel quality, and measurement of service quality
- Automatic routing
- Support for broadcast messages used for load control and tariff switching
- Error detection and correction
- Automatic repetition of messages identified as 'faulty'
- Integrated repeater function
- Remote parameterization
- Prioritized terminal units
- Standardized interfaces for RTUs, meters and data concentrators
- Network management support

Outlook

As a result of deregulation of the energy markets power producers are having to cope with a whole range of new challenges, underscoring the need for large-area acquisition of different types of data. ABB developed the DartNet communications concept for just such tasks. Special emphasis is placed on the reliability of the data transmission. During development of the DartNet DLC system several technical obstacles had to be overcome, a fact that is borne out by the many new patents that have been taken out. The broad functional capability of DartNet makes it suitable for numerous new applications.

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