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EVALUATION OF THE QUESTIONNAIRE FIBER OPTICS FOR POWER UTILITIES COMMUNICATIONS

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1990

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GLOSSARY AND DEFINITION OF TERMS

APD
Avalanche Photodiode - inherently high gain photo detector having a higher effective response than PIN diode.

CCIR
International Radio Consultative Committee.

CCITT
International Telegraph and Telephone Consultative Committee. An organisation to establish standards for inter-country operation on a world wide basis.

CEPT
Conference of European Posts & Telecommunications Administration.

dB
Decibel is the relative logarithmic ratio of two electrical or optical powers.

dBm
Absolute level of power relative to 1 mW expressed in decibels.

DIN
German national standard - 'Deutsche Industrie-Norm'.

IEC
International Electrotechnical Committee.

IEEE
Institute of Electrical and Electronic Engineers.

LAN
Local Area Network.

LASER
Light Amplification by Stimulated Emission of Radiation - Spontaneous emission occurs as a result of recombination of excited electrons and holes. In a laser diode photons are predominantly generated by stimulated emission. The stimulated photons are coherent with the generating photons and have the same wavelength and phase. The result is a narrow spectrum unlike LED's which have a wide spectrum.

LED
Light Emitting Diode - A device for generating light by recombination of electrons and holes inside a p-n junction. Each recombination releases a photon.

M Fibre
Multi Mode Fibre includes both step-index and graded index types. In the case of step-index fibre the light is guided by total reflection at the core/cladding boundary. The core diameter is typically 100μm allowing a significant range of internal reflection angles. Low band-width is a significant disadvantage of step-index fibres due to the wide range of propagation delays. Fibre is limited to 850nm systems with a bandwidth of 20 MHz x km. Graded index fibre achieves a higher bandwidth by providing the core with a bell shaped index profile across its diameter which bends the light rays towards the line of the fibre thus reducing the number of propagation modes. Typical core diameter 50μm and bandwidth 1GHz x km.

MTBF
Mean Time Between Failures - normally expressed as the average number of hours an item or system is expected to run without breakdown.

MTTR
Mean Time to Repair - average time taken to return to service the faulty item or system. Both MTBF and MTTR have a direct bearing on System

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \times 100\%$$

OPGW
Optical Ground Wire - an alternative description for a composite conductor where fibres are embedded within the power conductor.

OTDR
Optical Time Domain Reflector - an instrument for the characterisation of fibre attenuation, uniformity, splice loss, breaks and length.

PIN
Generic term for a Photon energy absorbing detector. Material of the device is chosen according to the maximum efficiency at operating wavelengths e.g Silicon for 850nm, In GaAs for 1300 nm.

PLC
Power Line Carrier - Carrier frequency equipment operating in the 30 - 500 kHz frequency range for conveying telecommunication signals over power lines.

SM Fibre
Single Mode (also termed Mono Mode) fibre - a fibre with a small core diameter of 5-10μm which forces the light propagation into one mode only. This fundamental mode travels in a straight line without being reflected at the boundary between core and cladding. Bandwidth 100 GHz x km.

VDE
Association of German Electrical Engineers - 'Verband Deutscher Elektrotechniker' producing a wide range of standards.

INTRODUCTION

Today optical fibre cables are commonly used in public telecommunication systems because of the advantages of digital technology in general and the specific advantages of optical fibres. In these applications, the main reason for the introduction of this technology is the large communication capacity provided by the new medium.

As typical power utility applications do not need very high capacities, there is not such an economic pressure to introduce optical fibres in this field. However, the almost complete absence from any electromagnetic compatibility problems is a very attractive feature for power system applications too.

Although the basic technology is well established, its application to power systems has shown specific problem areas. The most critical aspect has been the installation of optical cables on power lines, which has often become a necessity due to the fact that no ducts available, no other rights of way available or even cost considerations.

With respect to the high security and reliability requirements in power systems a serious and critical evaluation of any new technology is essential. It was therefore decided to establish a corresponding working group 04 "Fibre Optic Systems" in CIGRÉ SC35. Its objectives are to collect and to report on such systems in order to give the necessary information for users and manufacturers.

To obtain the necessary data, the working group distributed a questionnaire to all 24 CIGRÉ member countries in March 1988 for replies to returned by 18 September 1988.

The introduction of a new technology for telecommunications not only raises a large number of technical questions. Users may be faced with new economic and even legal considerations. Operational questions and general introduction strategies are also of great interest.

The questionnaire therefore covers a very wide field, and has consequently required a considerable effort by all answering companies. The working group thanks all contributors for their valuable work.

Many fields covered by this large questionnaire are not applicable to cable manufacturers. A special reduced version was therefore distributed to these manufacturers.

Although, during the evaluation, the working group tried to reflect as correctly as possible the answers given in the questionnaires, some interpretation was necessary. The following rules were applied:

- Obviously wrong answers were cancelled.

- If ranges were given in the answers, the mean value was taken in the evaluation.

Exception: Evaluations showing maximum or minimum values.

Intervals in figures are to be interpreted as follows: Answers at the upper limit are considered to be in the interval, answers exactly at the lower limit of the interval are not.

Figure 0.1 shows, how many questionnaires have been returned from the different countries. A total of 62 utilities, one consultant and 15 manufacturers from 17 countries have replied.

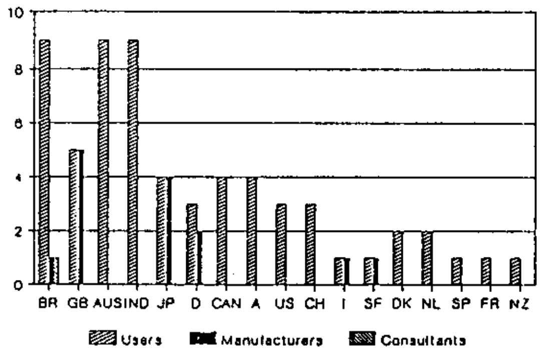

Figure 0.1: Number of questionnaires returned from different countries

In an addendum to the questionnaire sent to utilities the length of transmission lines operated was requested. The total length for all answering utilities is plotted countrywide in figure 0.2.

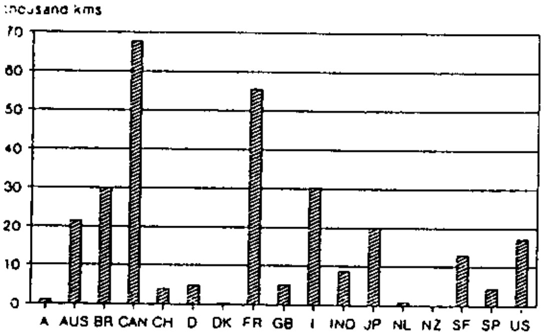

Figure 0.2: Total length of transmission lines operated by answering utilities per country

The answers given allow a comparison to be made with the total line length operated by the answering utilities as given in CIGRÉ SC35 telecommunication statistics [1]. The quotient of the two values can be considered as the coverage index of the questionnaires. The overall coverage index calculated for all the countries, from where questionnaires were returned, is about 25%.

Amongst the ten biggest utilities in the world (according to· kWh sales) the following utilities have sent back a completed questionnaire:

- EDF (FR)
- CEGB (GB)
- TEPCO (JP)
- ENEL (I)
- Hydro Quebec (CAN)
- Ontario Hydro (CAN)
- TVA (US)
- Chubu Electric Power Co. (JP)

Therefore, the figures given in this report may be considered representative, although in some countries the situation may differ quite significantly.

1. OVERVIEW

Question 1.7: What is the total route length of cable that is planned to be in service by 1988.. 1996?

Among the 78 answered questionnaires, 62 are from power utilities and 16 from consultants and cable and equipment manufacturer. 18 (32%) of the utilities do not own any fibre optic communication system and even 7 of them (16 %) do not plan any future experimentation. These latter consumers are mainly located in developing countries.

The length of fibre optic cables set up or planned to be set up by utilities before 1/1/89, is about 15,540 km.

Generally cables have a capacity of 6 fibres and therefore multiplying by six gives the length of individual fibres set up: 100 000 km. Some American and Japanese cables may even have 10, 12 or 48 fibres in them.

Figure 1.1 provides the number of companies per length of cable set up. This histogram shows the Japanese technological advance: the first four fitters represent Japanese companies which together provides 91 % of the total length by themselves.

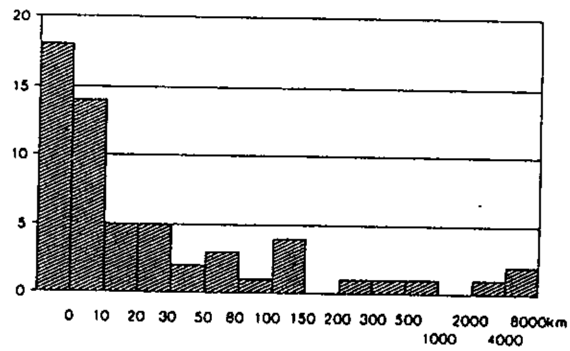

Figure 1.1: Number of answering power utilities versus length of optical fibre cables installed

Figure 1.2 shows the development in installed length as reflected in the answers from the questionnaire. When interpreting the graph it is important to bear in mind its built-in problems. First of all the companies may have different planning horizons, second the development in price structure may heavily influence the development, third the political development in the area of telecommunications may also change the plans of the companies. All these factors apply to both short and long planning horizons.

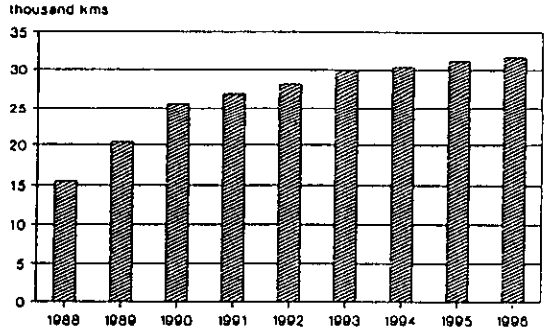

Figure 1.2: Forecast of optical fibre cables installed

Question 1.9: What are the major factors that influence your rate of adoption of fibre optic communication systems?

The inquiry shows very plainly the reasons which induce the power utilities to prefer the optic fibre to other communication ways. Some utilities indicated multiple reasons.

About 60% stressed the reduction of price (on per channel basis) gained by the use of fibre optic.

Then about 25% acknowledge a greater fibre optic reliability and a greater equipment availability.

Then 20% consider the greater channel capacity and the independence from the PTT.

Then 10% identified the problem of frequency saturation of Radio & PLC.

It must be in mind that price reduction by using optical fibre, is justified only for large capacities of communication, so financial assessment is on the basis of low cost per channel.

Point 1.9 shows that the economical and technical factors influence primary the adoption of fibre optic communication systems.

2. RANGE OF APPLICATION OF FIBRE OPTIC COMMUNICATIONS SYSTEMS

Question 2.1: What are the fundamental advantages/ disadvantages to you in the use of fibre optic communications systems?

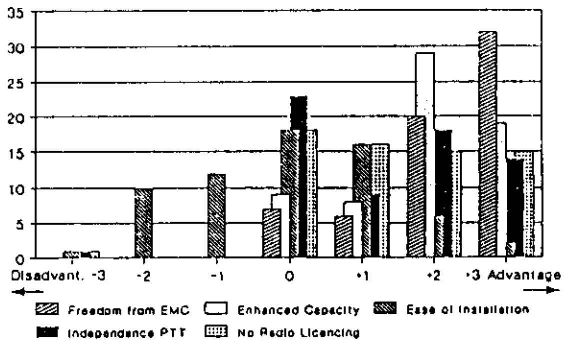

Figure 2.1: Number of replies dependent on how the features were rated 2.1 a - 2.1e

Question 2.1a: Freedom from Electromagnetic Compatibility (EMC) problems.

This characteristic of fibre optic systems received the highest positive evaluation at 89%. Approximately 49% of those questioned considered it a significant advantage; 31% considered it to be an important advantage and 9% a small advantage.

Question 2.1b: Enhanced Communication capacity

The higher communication capacity associated with fibre optic transmission also achieved a high rating with 86% positive replies. For 29% it was a significant advantage, for 45% it was important, and for 12% it offered a small advantage.

Question 2.1c: Ease of Installation

Opinion was divided on the advantages and disadvantages. Positive and negative ratings were approximately equal.

Question 2.1d: Independence from Public Telecommunications Operators

The independence of one's own communications was given a high rating. 63% of the replies were positive, the rest indifferent.

Question 2.1e: Freedom from Radio Licensing Problems.

The replies to this question were clearly positive (72%). The remaining 28% rated advantages and disadvantages equally.

Question 2.2: What are the areas of Application for your fibre optic systems?

The replies to this question provide an initial, non-qualified overview of the telecommunications services employed by the users.

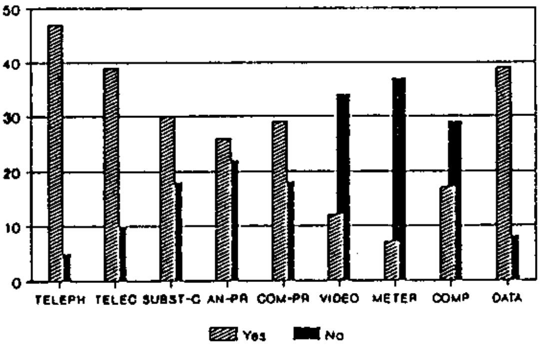

Figure 2.2: Number of yes/no statements concerning the presence of the respective service telephony, telecontrol, substation control, analogue protection, command protection, video, bulk supply metering, main frame computer links and/or data transmission.

The most frequently employed services are (as is to be expected) telephony 90%, telecontrol 80%, substation control 63%, command protection 62%, and data transmission 83%. But a relatively large percentage of users already employ the services predestined for fibre optic transmission such as analog protection 54%, video transmission 26%, and mainframe computer links 37%.

Further specific questions concerning the number of channels, channel bit rate etc were answered in greater detail under item 3.1.w.

Question 2.3: What are the typical system requirements for each of the areas of application identified in question 2.2?

The question concerning the number of channels, the channel bit rate, and the distance range were asked again under item 3.1.w and replied to there in greater detail. The evaluations are therefore to be found in that section.

Values for the delay response time were only supplied in a few questionnaires; they also range very widely. For this reason it was not possible to make a meaningful evaluation.

Information on the system availability requirement was provided in 23 cases; 14 of the replies are in the range of 99.9 - 99.999%. Most of the users (90%) make no distinction between the individual types of services.

As regards the system availability experienced (MTTR), 8 questionnaires provided information that can be evaluated. Values from 2 to 9 hours were given for the MTTR.

Question 2.4: How are the communication links shared in the case of multiple service applications?

Most of the questions answered indicate that the various services are operated using time-division multiplex (TDM).

The service combinations that occur and the frequency of their occurrence was evaluated in section 3.1.w.

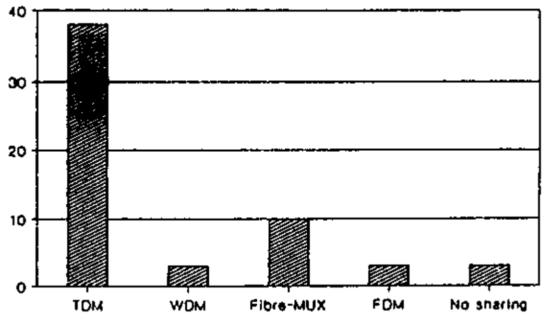

Figure 2.3: Multiplexing in the case of multiple service applications

Alongside TDM transmission, in several cases (10 users) separate fibres in a common cable (fibre multiplex) were also employed for the different services. In the above applications a separate fibre is most frequently provided for protection transmission. Three users have a separate fibre available for each service.

Under "Other services", analog frequency-division multiples (FDM) was specified in 3 cases.

Question 2.5: What are the main disadvantages to you in the use of fibre optic communications?

In the comments referring to point 2.5 of the questionnaire the arguments speaking against the use of optical fibres were discussed; the arguments occurring most frequently were:

- The high cost of the optical fibre cable and its installation in existing systems as compared to radio relay and PLC systems, especially in the case of long distances (>30 km) and systems with low transmission capacity.

- The difficulties arising from maintenance and repair, especially of the optical fibre cable. Personnel must be trained for splicing, and the equipment required (splicing device, reflectometer) is expensive. The meantime of repair is very high for both, OPGW and buried cables. In the case of open-wire lines, it might also be necessary to interrupt high-voltage transmission for maintenance and repair purposes, which would result in additional costs.

- Important communication links could be endangered by vandalism, gun shots or the breaking down of transmission towers.

- Several times objections were made to the great number of different types of optical fibre connectors.

3. PRACTICAL EXPERIENCE AND FUTURE REQUIREMENTS

Question 3.1: What practical experience do you have in fibre optic telecommunication technology and what systems are you planning for the future?

Users may operate a large number of links, so that it is not possible to collect all details about all the links. However, different applications and technological generations may result in quite different system parameters for different links of one user. It is therefore reasonable to group similar solutions into types of systems. In section 3.1 the users were asked to specify the types of systems considered.

A total of 201 system types are given in the questionnaires, of which more than half refer to existing systems (going back as far as 1980), the others to systems installed in 1989 or later.

All figures given in part 3.1 refer to this number of existing or planned system types, if not specified otherwise.

Question 3.1.a: Date of commissioning or planned future date

The distribution of the answers to this question is shown in figure 3.1.

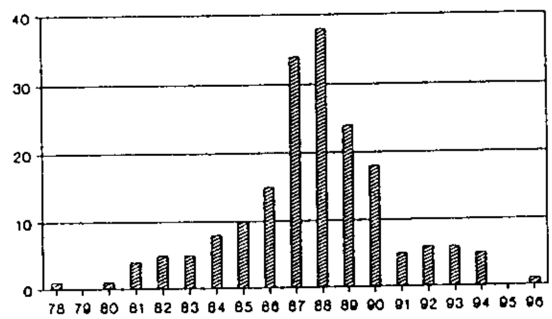

Figure 3.1: Number of system types versus date of commissioning or planned future date

Question 3.1.b: Communication category and number of systems

In order not to mix different applications, a classification into three categories of systems is made:

- Intrastation communications systems - ie. communications within substations

- Interstation communications systems - ie. communications between substations

- Network communications systems - ie. interstation communications links joined together

Only 5% of the system types given in the questionnaires describe intrastation, all the others interstation and network communications systems. This reflects the fact that interstation systems have reached a much higher degree of maturity than intrastation systems. The statements and conclusions taken from the questionnaires are therefore representative for interstation communications, but not for future developments of intrastation applications.

5% of the given system types are analogue systems, mostly carrying frequency division multiplexed telephone channels. In an existing analogue environment such a solution seems still to be justified if an isolated fibre optic link has to be provided. For larger systems, of course, digital solutions are much more advantageous.

Question 3.1.c: Cable route length (km) (or range if more than 1)

Figure 3.2 shows the total route length of fibre optic communication systems (only interstation and network types considered), including regenerators if required. The maximum length of existing systems is 1200km, of future systems 1000km. The mean route lengths are 26km (existing) and 51km (future). These system lengths are still relatively short, but a trend towards longer systems can be seen clearly.

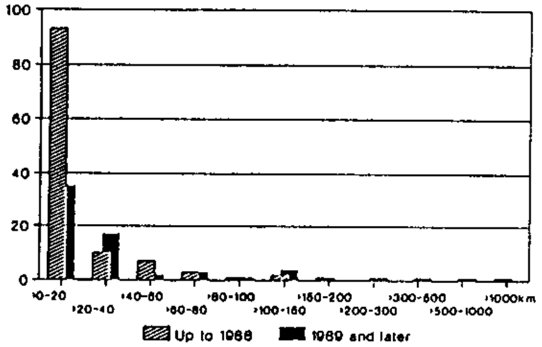

Figure 3.2: Number of existing and future system types versus total route length

In only 14% of the types the route length is not identical to the unrepeated section length (see question 3.1.d), i.e. regenerators are used on these routes. The distribution of system types as a function of (repeated) route length is given in figure 3.3. Again, it can be seen, that the routes with regenerators will be significantly longer in future than they are today.

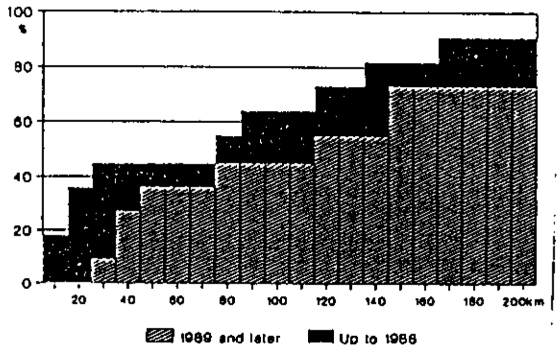

Figure 3.3: Distribution of system types as a function of route lengths for types using regenerators (100% corresponds to all given types with regenerators)

Question 3.1.d: Unrepeated section lengths (km)

Figure 3.4 shows the length of unrepeated sections of the digital interstation (and network) system types.

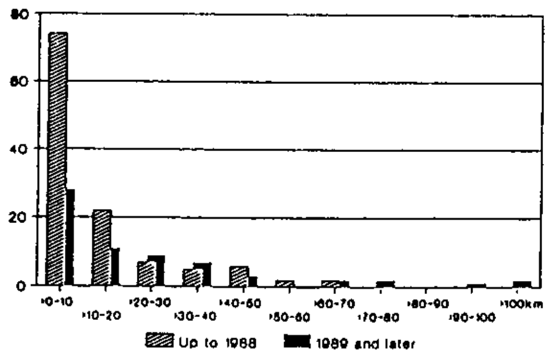

Figure 3.4: Number of existing and future system types versus (unrepeated) section length

The mean values of the unrepeated section lengths are 12 km (existing) and 25 km (future). Most types cover small distances, but it is evident, that future types tend towards longer distances above 10 km. The section length of existing types is mostly shorter than 10 km. This may reflect, that the questionnaires also cover a lot of experimental systems built in the early 80s, which usually were very short systems.

The trend towards typical distances of 20 - 40 km may have different reasons:

- It is a typical distance between substations.
- For typical applications the cost crossover point, below which optical fibre systems are more economic than other media, is located in this region.
- This distance may be easily overcome without regenerators using standard technology.

The systems with section lengths around 100 km are future systems not yet fully specified (wavelength, fibre type, bitrate are missing).

Question 3.1.e: Type of cable installation, e.g. OPGW, wrapped, buried, ducted, aerial

Because of the varying conditions under which fibre optic systems have to be planned, different cable installation methods are used by power utilities. The distribution of the type of cable installation used by the different system types is shown in figure 3.5. In some cases more than one basic cable type has to be combined on one communication section, e.g. buried cable from a telecontrol room to a switchyard and OPGW from the switchyard to a remote location. In future, more cables on power lines (e.g. OPGW) will be used, and less buried or ducted cables. This reflects again a tendency towards longer sections, as can be concluded from figure 3.6.

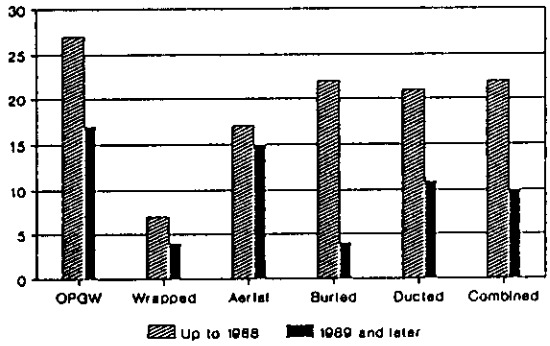

Figure 3.5: Number of existing and planned system types for different cable installation methods

The average route length for each cable installation method is shown in figure 3.6. OPGW and, in future, wrapped cable are typical installation methods for long, aerial cable for medium and buried and ducted cables for short distance systems. The interesting change from a short distance method to a long distance method, which can be seen for wrapped cable systems, may be due to the fact, that up to now such systems were mainly experimental systems. However, careful interpretation must be made as the number of systems given is small (see figure 3.5).

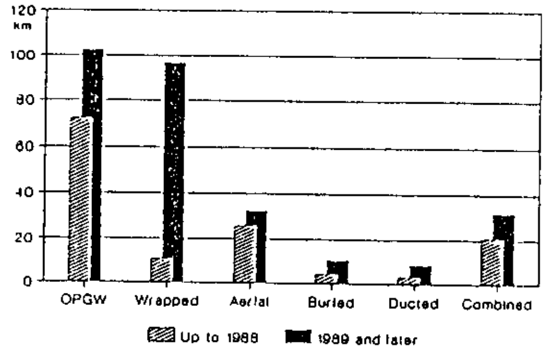

Figure 3.6: Average route length for different cable installation methods, for existing and planned systems

Question 3.1.f: Manufacturer of cable

A total of 33 different manufacturers are given. Figure 3.7 shows, how many manufacturers produce cables of a certain technology. OPGW and aerial cables, as well as cables for buried or ducted installation are produced by many manufacturers, whereas wrapped cable is a specialized technology offered by just a few of them. Obviously, for future systems the manufacturers are often not yet defined, so that very few answers were given. It is therefore not possible to conclude about a certain trend.

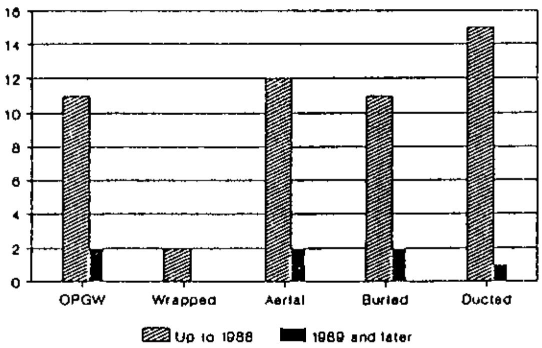

Figure 3.7: Number of different cable manufacturers for different installation methods

Question 3.1.g: Type of fibre, e.g. single mode, multimode-step/graded index

A trend from graded index multimode fibres towards single mode fibres can be observed.

Up to 1988, 63% of all system types used graded index multimode fibres, while this percentage is reduced to 28% for the period 1989 and later. This reflects again the trend towards longer distances as well as the fact, that single mode fibres are no longer more expensive and more difficult to handle (splicing, etc.) than multimode fibres.

Question 3.1.h: Number of fibres in cable

The number of fibres used in an optical cable is a result of a large number of considerations, such as cable construction, number of different users with separate fibres, reliability, cost and others. In existing systems, the most common fibre number is four, as can be taken from figure 3.8. This is also true for new systems, but more than four fibres are being much more widely used. Further evaluation reveals, that the number of fibres is not correlated with the link distance.

A reason might be the reduced cost of fibres today, which therefore has less influence on the overall cost of the cable.

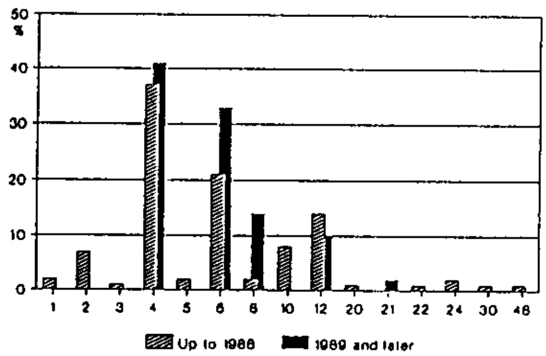

Figure 3.8: Percentage of number of fibres per cable

Question 3.1.i: Manufacturer of fibre

A total of 23 different manufacturers are given, 20 of them producing multimode, 14 single mode fibres. These manufacturers can be grouped according to their annual fibre production as given in figure 3.9. (This parameter was not asked for in the questionnaire - it was therefore necessary to take it from other sources).

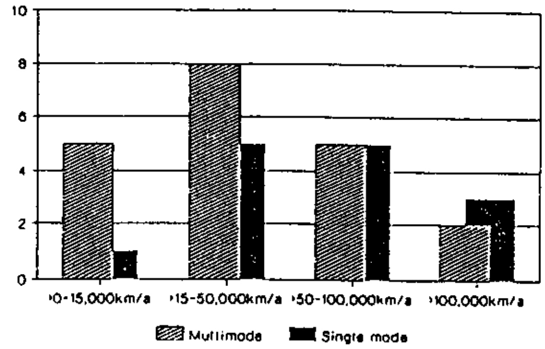

Figure 3.9: Number of different manufacturers producing multimode or single mode fibres

The investment required in manufacturing equipment to produce single mode fibre is high and therefore its production is confined to the larger manufacturers. Having made the investment production costs are now less than for multi mode fibre and therefore singlemode becomes a natural choice for transmission systems offering wider bandwidth and lower alternation.

Question 3.1.j: Wavelength used, e.g. 850, 1300 or 1550 nm

In figure 3.10, the optical wavelength used is given. It changes significantly for the future. The percentage of system types using 1300 nm technology is increased in the period 1989 and later, as compared to the 850 nm technology. This is not astonishing, as 850 nm is a technology for short links and single mode fibres are often not specified at this wavelength. Among 120 systems given in the period up to 1988 42 were operational at 850 nm, 76 at 1300 nm and 2 with 1550 nm technology. For the 45 systems in the period 1989 and later the corresponding figures are 10 (850 nm), 33 (1300 nm) and 2 (1550 nm). 1550 nm is still a special technology, and for the future 1300 nm seems to be the standard solution.

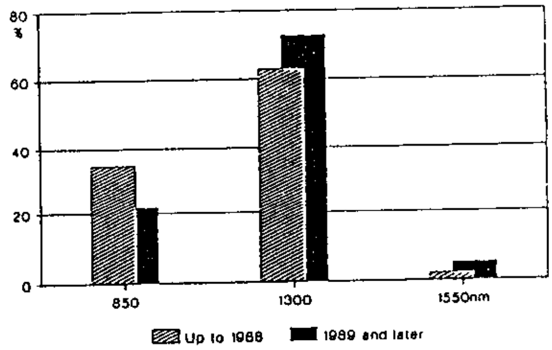

Figure 3.10: Percentage of existing and planned system types using different optical wavelengths

Question 3.1.k: Attenuation (dB/km)

The distribution of the attenuation per unit length of the fibre (without splicing, etc.) is shown in figure 3.11. Obviously wrong values are not considered. The mean values are as follows:

for 850 nm : 3.54 dB/km
for 1300 nm : 0.67 dB/km
for 1550 nm : 0.40 dB/km

A detailed analysis of the questionnaires shows that these values probably represent a mixture between typical or measured performance and worst case guarantee values. Therefore, they are relatively high. A comparison of these mean values for the two periods up to 1988 and 1989 and later shows that the 850 nm mean attenuation for each km decreases from 3.73 to 2.79 dB, and the 1300 nm attenuation from 0.68 to 0.63 dB. Obviously, the 850 nm values were influenced by early prototype fibres with higher attenuation.

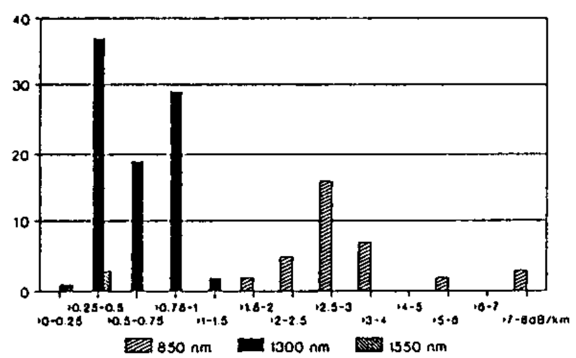

Figure 3.11: Number of existing and planned system types using optical fibres in different ranges of attenuation per unit length

Question 3.1.l: System route attenuation including splice losses (dB/km)

From the system route attenuation the attenuation per unit length including splices can be calculated. Again, obviously wrong values are not considered. This results in the following mean values:

for 850 nm : 4.86 dB/km
for 1300 nm : 0.89 dB/km
for 1550 nm : 0.45 dB/km

Again, these values probably represent a mixture between typical or measured performance and worst case design values. Therefore, they are relatively high.

Question 3.1.m: Location of splice joint boxes, e.g. tower top, buried, etc.

Figure 3.12 shows, where splice joint boxes are located in case of overhead optical fibre cable (OPGW, wrapped, aerial or combined). A clear majority prefer to locate splice boxes containing the fibres on top of towers, which normally saves cable length if the splicing is also carried out at the top of the tower. (At least one system carries out splicing at ground level and then secures the splice housing at the tower peak winding the excess cable within the housing).

This reflects the fact, that climbing the tower by the splicing technician is not considered as a critical factor.

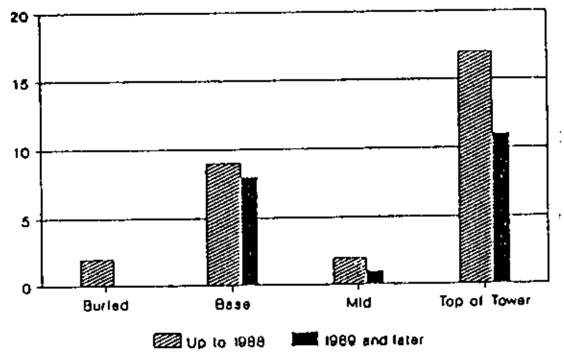

Figure 3.12: Number of existing and planned system types with overhead cables using splice joint boxes at different locations

Question 3.1.n: Optical transmitter LED/Laser, power output

For 850nm systems 83% of system types use LED as transmitter elements, and only 17% laser diodes. For 1300nm systems the relative values are 39% (LED) and 61% (laser diode). Two 1550nm systems use LED and four use laser diodes. The preference for LED on 850nm results from the fact that these systems are typically older installations. Traditionally the reliability of laser diodes was not sufficient so that LEDs were preferred. For new systems, often using monomode fibres, laser diodes are preferred, at least for medium and long distance links.

Figure 3.13 reflects the typical range of emitted power for 1300nm optical sources (LED and laserdiode).

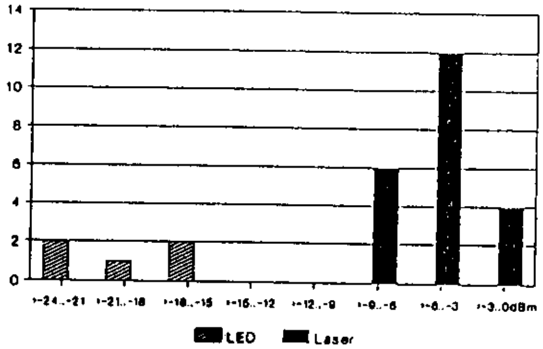

Figure 3.13: Number of existing and planned system types using 1300nm LED and laser diode transmitters in different ranges of emitted power

Question 3.1.o: Optical receiver APD/PIN, sensitivity (dBm)

At 850nm, about half of the system types use PIN diodes, the other half APDs as receiver elements. In one system with very low bitrate, photo transistors are used. At 1300nm 61% use PIN diodes and 39% APDs. Among the three system types running at 1550nm, two use PIN diodes and the other one APDs.

As the sensitivity of optical fibre receivers depends on the bitrate, a relative sensitivity S_{rel} is given in figure 3.14 instead of the absolute sensitivity S_{abs}. Like this, the values are comparable. S_{rel} is the calculated sensitivity at a reference bitrate of 2Mbit/s, using the following formula:

$$S_{rel} = S_{abs} - 5*\log(\text{bitrate}/2\text{Mbit/s})$$

The figure shows, that APDs perform better than PIN diodes at 850nm, whereas at 1300nm no significant difference can be observed.

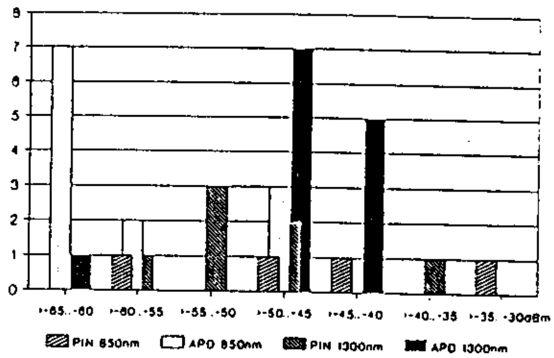

Figure 3.14: Number of existing and planned system types using 850nm and 1300nm PIN and APD receivers in different ranges of relative sensitivity

Question 3.1.p: Duplex transmission on single fibre? YES/NO

Only two utilities answer "YES" for one or two system types. In one case these are future links over 20km. The other respondent mentions a 3km link to be installed by 1990. As none of these systems is operational and only two utilities deal with this technology, it can be concluded, that - at least for interstation links - duplex transmission is still in the experimental phase, with uncertain outcome.

Question 3.1.q: State make of demountable optical connectors used

A large number of manufacturers is given. However, often only the manufacturers and not the connector types are indicated. As many manufacturers produce different types of connectors, it is difficult to conclude about the relative importance of the connector types. With this restriction in mind, the following statements can be made:

In existing system types (up to 1988) the most frequently used demountable connectors are with multimode fibres FC (10 system types), Diamond (10), SMA (8) and DIN (8), and with single mode fibres FC/FC-PC (15) and DIN (13).

In new system types (1989 and later) the most frequently used demountable connectors are with multi-mode fibres Diamond (6) and with single mode fibres FC/FC-PC (6) and DIN (5).

Question 3.1.r: State number of regenerators used

In a total of 13 system types with route lengths ranging from 16 to 1200km (mean value: 209km) a total number of 39 (+ a not specified number for the 1200km route) regenerators are used.

Among these 13 system types, 7 have been installed up to 1988. These existing types use a total number of 24 (+ a not specified number for the 1200km route) regenerators.

Question 3.1.s: Regenerator location (e.g. building, tower mounted, buried, etc.)

In 10 (4 existing) of a total of 13 system types using regenerators, these are located in buildings. A shelter is considered to be a building. In 4 (2 existing) system types regenerators are mounted on towers.

Question 3.1.t: Regenerator power sources

In 4 (3 existing) of a total of 13 system types using regenerators, AC power supply is provided. Two of them (both existing) mention a diesel backup. 5 system types are solar powered (1 existing type with 1 tower mounted regenerator). In one case DC supply is given.

Question 3.1.u: Terminal equipment power source, e.g. AC supplies, battery, etc. (state volts)

In a total of 152 system types, this question is answered. In 16 system types two power sources are given. The different power sources used are shown in figure 3.15.

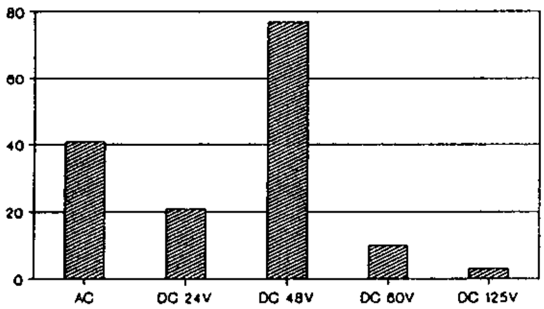

Figure 3.15: Number of existing and planned system types using different terminal equipment power sources

Question 3.1.v: What is the system bitrate, e.g. 565, 140, 34, 8, 2 Mbit/s

The system bitrate is dealt with in figures 3.16, 3.17 and 3.18. The majority of existing system types uses bitrates of 1.5/2 Mbit/s or 6/8/10 Mbit/s, where the lower bitrate is dominating. Systems installed 1989 and later, however, show an equal number of types with these two bitrates - an indication for a tendency towards higher capacity systems. Nevertheless, real high capacity systems with bitrates of 32 Mbit/s and more are still not very frequent. This shows, that typical power utility requirements can be covered with lower capacity systems. 78% of all system types use the "European" standard bitrates 64kbit/s, 2, 8, 34, 140Mbit/s and 18% use the "American/Japanese" standard bitrates 56kbit/s, 1.5, 6.3, 32, 44, 100Mbit/s. 4% use other, non-standard bitrates.

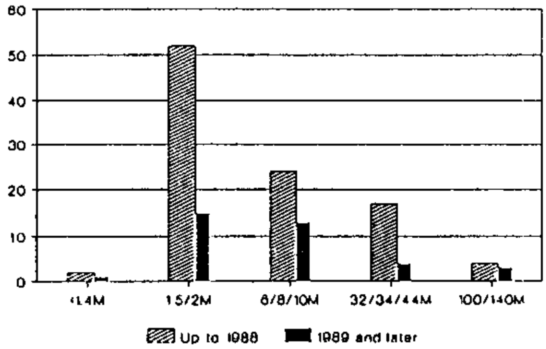

Figure 3.16: Number of existing and planned system types for different system bitrates

In figure 3.17 the mean length of the possibly repeatered link is plotted for different system bitrates. It shows, that the high capacity systems are used for the long distance backbone telecommunication links. The mean length for all bitrates is higher in future than it was before 1989. This probably results from better technology allowing for higher unrepeated section lengths (see also figure 3.18), and from decreasing cost, pushing the cost crossover distance (where cost for optical fibre systems equals that of conventional technology) to higher values. This aspect is particularly evident for 6/8/10 Mbit/s systems.

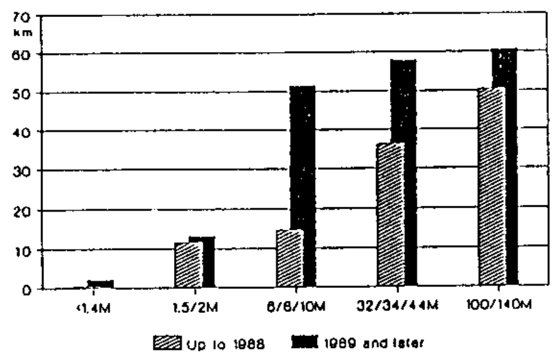

Figure 3.17: Average link length for different bitrates

In figure 3.18 the maximum length of unrepeated sections for different bitrates is given. For systems with bitrates 6Mbit/s or higher it is obvious, that technology allows higher maximum section lengths for new systems (installation 1989 and later), as compared to older systems. For 1.5/2Mbit/s systems the trend is opposite, obviously not due to technology, but possibly due to the fact that these systems are still used on shorter links (see figure 3.17) than higher bitrate systems.

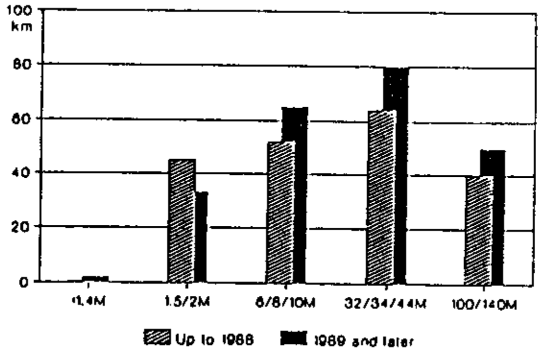

Figure 3.18: Maximum length of unrepeated sections for different bitrates

The correlation between cable installation method and system bitrate is shown in figure 3.19. For OPGW and aerial cables the most frequent bitrate is 6/8/10 Mbit/s, whereas for the other installation methods it is 1.5/2 Mbit/s. The typical long distance installation methods (see fig 3.6) OPGW and aerial cable are also those used on links with higher bitrates.

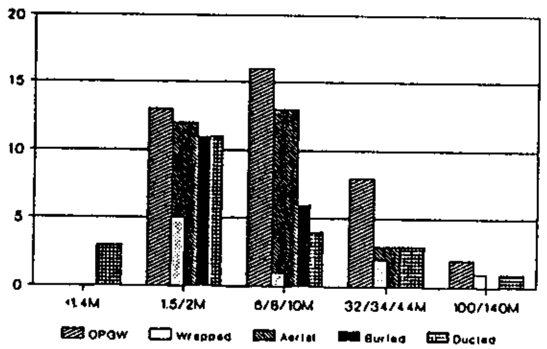

Figure 3.19: Number of existing and planned system types for different system bitrates and cable installation methods

Question 3.1.w: Indicate the number of channels carried for each of the following services together with their signalling rate and type of user interface, e.g. CCITT G.703 or application specific (as for say teleprotection)

The following Services have been specified in the questionnaires: telephony (TELEPH, single channels), 30 channel trunk lines for telephony with direct 2Mbit/s access to telephone switch (2M-PAX), telecontrol (TELEC), substation control (SUBST-C), analogue protection (AN-PROT, e.g. phase comparison, longitudinal differential protection), transmission of protection commands (COM-PR), video (VIDEO) and data transmission other than telecontrol and substation control (DATATR).

The number of the given system types that carry these Services are shown in figure 3.20. Telephony, telecontrol, protection and data transmission are the most frequent Services, substation control, video and direct 2Mbit/s trunks between switches are not so frequent. The relative importance of data transmission as compared to telephony is higher in new systems than in older ones.

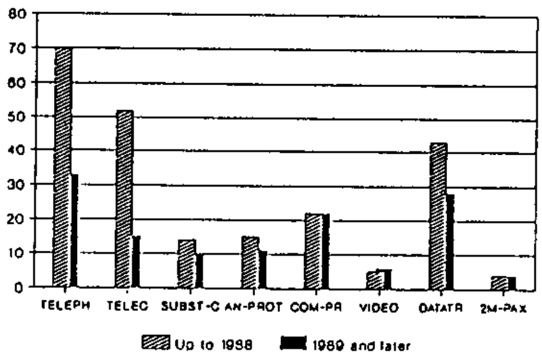

Figure 3.20: Number of existing and planned system types carrying the Services - telephony, telecontrol, substation control, analogue protection, command protection, video, data transmission and/or 2Mbit/s PAX-PAX links

The same evaluation is made in figure 3.21, where the number of individual channels is given instead of the number of system types. In order to calculate the total number of channels, it is necessary to know the number of individual systems realized or to be realized per given system type. Although this question was asked in 3.1.b, it has not always been answered. It is therefore not exactly possible to calculate the number of channels covered by the answers in section 3.1. With this restriction in mind, it can be concluded from figure 3.21, that most channels are used for telephony (single channels), whereas channels carrying all the other services are less frequent.

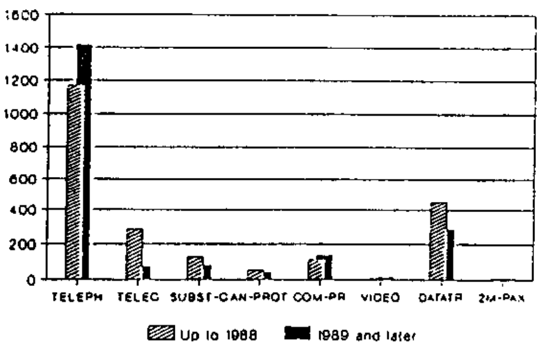

Figure 3.21: Total number of individual channels in all existing and planned System types carrying the services telephony, telecontrol, substation control, analogue protection, command protection, video, data transmission and/or 2Mbit/s PAX-PAX links

How many different Services are transmitted simultaneously on the same link is shown in figure 3.22. The number of system types given in the questionnaires is plotted as a function of the number of different services to be transmitted. It can also be taken from this figure, how the individual Services-telephony, telecontrol or substation control, protection and data transmission contribute to this multiservice operation.

Typically, the fibre optic links operated by power utilities have to cover more than one Service, many of them are time delay and error sensitive ones, such as teleprotection and telecontrol. It is therefore justified to pay high attention to reliability and availability questions in connection with these links.

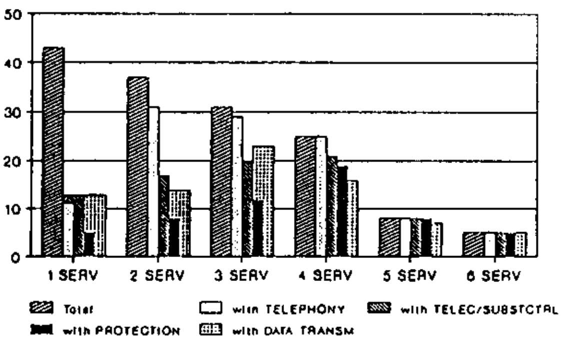

Figure 3.22: Number of existing and planned system types versus number of Services carried simultaneously

Figure 3.23 shows the mean link distance versus number of Services carried simultaneously on these links. It is obvious, that on expensive long distance links as many as possible Services should be combined together on the same link. On short distances, however, it may also be economical to use a link just for one or a few different Services.

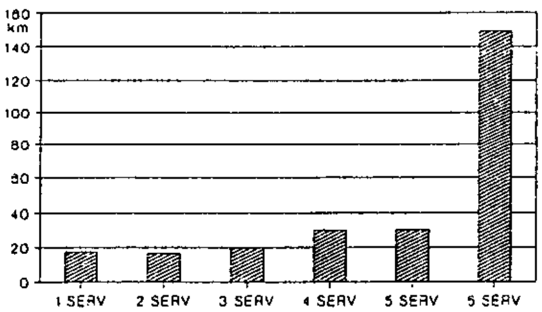

Figure 3.23: Mean link distance versus number of Services carried simultaneously

The basic bitrate of the bearer channel on digital systems for all applications (except video) is 64 kbit/s (or 56kbit/s - depending on the standard - see question 3.1.v). However, for the different services different interfaces to the telecommunication equipments are used. For telephony applications, standard telecommunication interfaces corresponding to the CCITT G-series recommendations are used almost universally. For the other Services it is interesting to know, how often the standard 64 kbit/s (or 56 kbit/s) interface CCITT G.703 is used, and how often Service specific interfaces are used which may not allow the full use of bearer channel capacity. E.g. for substation control, telecontrol and data transmission either CCITT V-type interfaces or even analogue interfaces with modem signals are still frequently used. The percentage use of the standard G.703 interface for different Services is given in figure 3.24. It can be seen that there are many Services where the application does not enable (or require) direct connection to the digital 64 kbit/s (or 56 kbit/s) telecommunication channel.

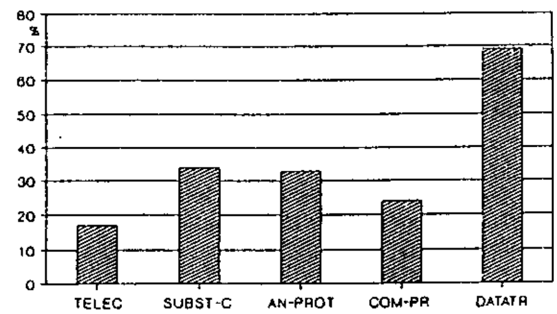

Figure 3.24: Percent number of channels on which the different services are using the bearer bitrate of 64 kbit/s (or 56 kbit/s) with CCITT G.703 interface

These values are based on the number of existing and planned system types and not on the total channel number. An approximate evaluation on a channel number basis shows a different picture: Only about one third of the high-speed data channels directly use the bearer bitrate of 64 kbit/s (or 56 kbit/s), the others use smaller values. For telecontrol and substation control systems, the user bitrate is in most cases smaller, often 1200 bit/s.

Question 3.1.x: Is there any system redundancy? e.g. duplicate hardware, alternate route, etc.

In more than half of the given system types redundancy is required to increase system reliability. For higher link distances this is even more important than for smaller distances, as can be seen from figure 3.25. Various concepts of realizing redundancy are applied (spare fibres, mostly with duplicate terminal hardware; alternate fibre optic route switching; alternate route switching using other media). No preference for one of these concepts can be deduced from figure 3.25.

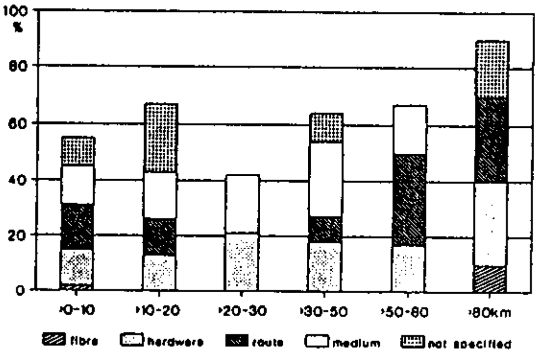

Figure 3.25: Use of different redundancy concepts (percentage of existing and future system types)

When planning a fibre optic communication system, it is of interest to know if the use of redundancy is correlated to the type of services carried on the system. Figure 3.26 shows, how many system types carrying a certain service apply redundancy concepts. It is obvious that if protection is involved redundancy is most often applied, whereas in systems carrying telecontrol or substation control redundancy seems to be less important. This latter fact is not easy to explain but it is clear that other factors (e.g. distance, total system capacity, etc.) also influence the application of redundancy concepts. For some services the availability is less critical, and the security can be assured by other means (e.g. error detecting or correcting codes), so that redundancy is less important.

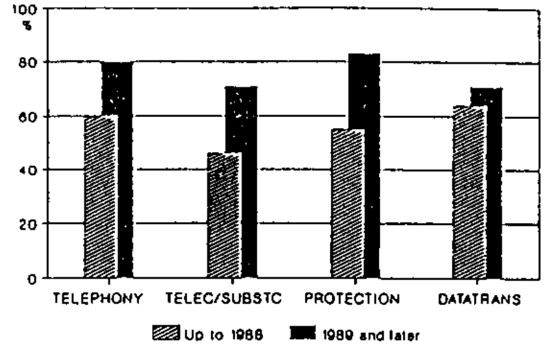

Figure 3.26: Percent number of existing and planned system types with redundancy concepts, as a function of services carried

Question 3.1.y: Is the fibre optic system an extension to an existing network? If so, what type of network is it extending, e.g. analogue, digital or fibre optic, etc.

See also evaluation of question 3.2.

About three quarters of all existing and future system types are an extension to an existing network.

Again three quarters of these existing networks are analogue, one quarter digital, about 10% are fibre optic networks.

Question 3.1.z: Have there been any failures or major technical problems? If yes, please describe

In ten of the 201 system types given in the questionnaires failures are reported. Most of these failures occurred in non-experimental systems, but some of them obviously in the erection or commissioning phase and not after the system was put into operation.

The following failures occurred:

- Equipment failure
- Midspan-joint failure
- Optical receiver failure
- Channel unit failure
- Loose connections on backplane
- Unplanned Cable excavations - 3 occasions
- Terminal card failures - many
- Fibre break - 2 occasions
- Wrapping problems - not a failure

Question 3.2: Do you have any individual link interconnection to form a network?

Two thirds of the utilities answering the relative question see a present and future need to interconnect individual interstation links to form networks. At present three quarters and in future half of them do this on an analogue basis, the others by direct digital interconnection.

Two utilities use transmultiplexers in existing systems, one will use them in future.

Question 3.3: Do you intend in the future to interconnect individual links to form a network?

See question 3.2.

Question 3.4: Do you use any kind of passive optical couplers?

Only three of a total of 39 respondents use passive optical couplers, two with LANs, one for wavelength multiplexing (850/1300 nm).

Question 3.5: Do you intend to use in the future any kind of passive optical couplers?

Four of a total of 31 respondents intend to use passive optical couplers, another three are studying this technology and have not yet taken a decision. Three utilities mention intrastation applications, one a LAN and one wavelength multiplexing (850/1300 nm).

Question 3.6: Do you have any special reliability and/or availability requirements?

Among the 37 answers to this question 15 are negative. Nine of the 22 respondents answering "yes" also specify the link availability. These figures vary from 99% to 99.9995%. The logarithmic mean value is about 99.99%.

The system reliability is specified by one respondent (>99.986%), and another one specifies MTBF-values for different system parts (terminal equipment: 7.5 years/equipment; OPGW: 600 years/km; regenerators: 5.7 years/equipment; aerial cable: 38 years/km).

In two questionnaires also the MTTR is given (<5 hours, 30 minutes).

Question 3.7: Do you consider encryption methods necessary for important information in fibre optic transmission?

Among the 38 answers only one is positive. In this case encryption is used for mainframe computer links.

Question 3.8: What international or national standards do you use when specifying fibre optic systems?

In figure 3.27 the numbers of utilities using the different standards and recommendations are given. 51% of the utilities use only international, 24% both international and national, 11% only national and 14% do not use any standards when specifying fibre optic systems.

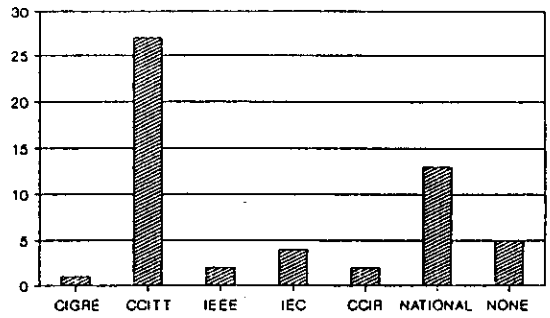

Figure 3.27: Number of utilities requiring different standards and recommendations (CIGRÉ guidelines, CCITT, IEEE, IEC existing standards and work done in Technical Committees, CCIR, different national standards, none or the standards applied by the suppliers)

Question 3.9: What equipment practice are you currently using?

Figure 3.28 shows the current and future use of different equipment practices. No significant difference between current and future use can be recognised. Many utilities use 19" practice, but also many do not consider this question of importance or use what the vendors offer.

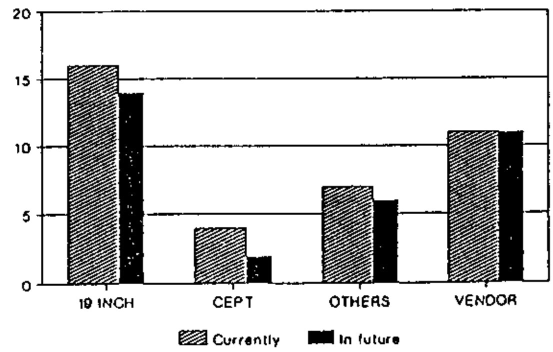

Figure 3.28: Number of utilities using different equipment practices, currently and in future (19 inch, CEPT, others, vendor specific or not of importance or different)

Question 3.10: What equipment practice do you intend to use for future systems?

See question 3.9.

4. CABLE TECHNOLOGY FOR FUTURE LINKS

This part concerned trends regarding the types of cable that could be used and what special features would be required by respondents for future communication links.

Four alternatives, namely composite conductor, self-supporting aerial cable, attached cable and ground cable were presented. In practice, almost all the respondents forecast the use of one or more of these alternatives. However, a clear preference emerges for the composite conductor, more specifically, when used as an earth conductor.

Question 4.1: Composite conductors with fibres embedded within the conductor

A large majority of respondents to part 4 (41 out of 46) express their preference for this solution, used as an earth conductor. The voltage range of the transmission lines on which to install this type was stated by 40 respondents. These voltage ranges are given in figure 4.1.

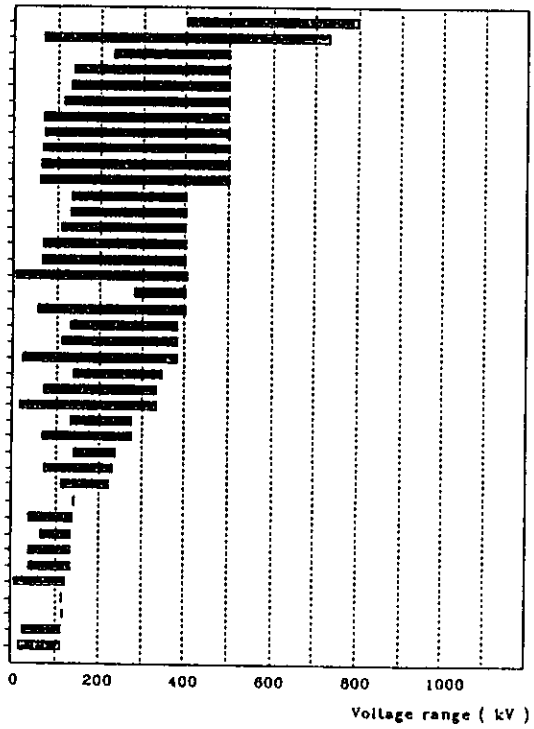

Figure 4.1: Line voltage ranges on which composite earth conductors are used by the answering utilities (each bar represents one answer)

Among the 41 respondents, 10 also consider the composite conductor as a phase conductor on lines whose voltages range from 10 to 735 kV. In particular, two important North American utilities, Bonneville Power Administration and Hydro Quebec, consider its use in the range of 230 to 500 kV and 69 to 735 kV respectively. The range of these voltages is given in figure 4.2.

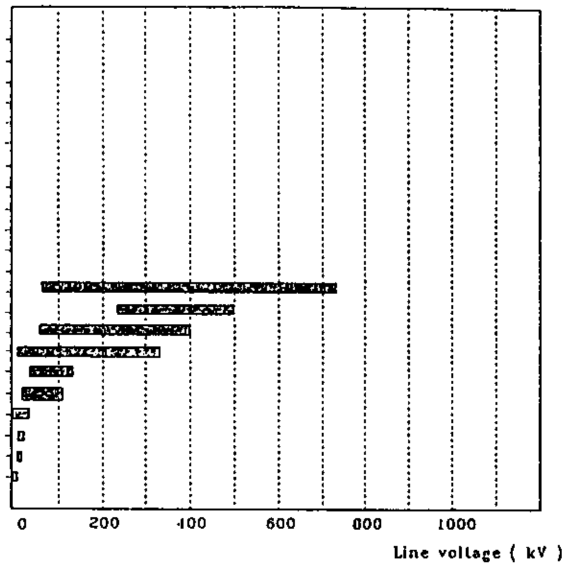

Figure 4.2: Line voltage ranges on which composite phase conductors are used by the answering utilities (each bar represents one answer)

As regards the features required and with reference to the earthwire solution, it may be noted that there is a trend to have a cable as similar as possible to the earthwire that it replaces. From the comments received, it is not possible to obtain a clear picture of the characteristics of the types of fibre preferred by the majority of the respondents, although a trend in favour of single mode fibres may be noted. In fact, preferences are expressed for both single and multimode fibres, and one respondent opts for both single and multimode fibres in the same cable (single mode for communication links, and multimode for power transmission line maintenance systems).

Question 4.2: Self supporting aerial cable, i.e. a separate cable strung between supports

Among the 33 respondents on this section, 27 give replies from which it is possible to deduce that this solution is or will be taken into consideration, the other 6 give replies that suggest this solution may not have been considered.

As regards the features of this solution, the results may be summarized as follows: 23 out of 33 respondents require the cable to be all-insulating, and only one (a Japanese utility) requires the cable to be semi-conductive, but no resistance range is supplied.

As regards the conducting strength member, this is not required by 22 of the respondents and definitely required by only 7 respondents.

The range of spans indicated by respondents is illustrated in figure 4.3.

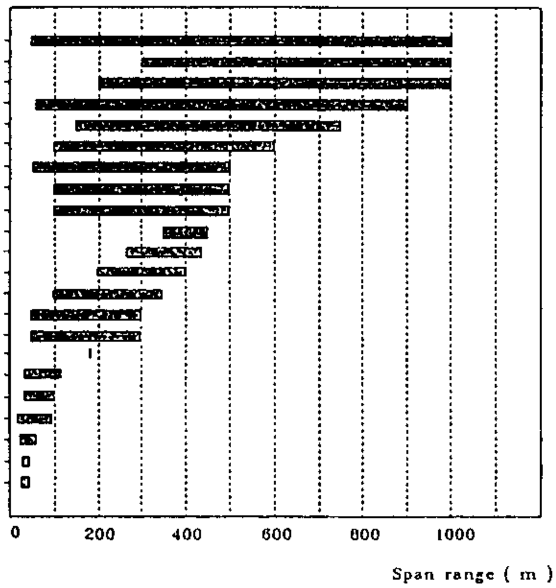

Figure 4.3: Span ranges for self supporting aerial cables considered by the answering utilities (each bar represents one answer)

It may be noted, that three respondents have declared a span of up to 1000 m. By contrast, only very few replies were given on maximum sag which were not always related to the spans, or on the maximum working stress. Roughly speaking this seems to range between 2 and 3 m for spans of the order of 100 to 120 m and to range between 10 and 20 m for spans in the order of 600 m. The maximum working stress ranges from 1,500 N to 44,000 N.

Question 4.3: Attached cable, i.e. a cable suitable for attaching to an existing conductor

Among 28 respondents answering this question, 27 state that this solution is or will be taken into consideration. How many respondents opt for different methods of attachment can be taken from the following table:

	earth conductor	phase conductor
wrapped around	18	11
clipped to	5	3

In the case of attachment of a fibre optic cable to a phase conductor, the conductor primary voltage range is from 11 to 400 kV. The main features required are ease of installation, endurance in respect of the combined action of the electric gradient, mechanical stress, and environmental attack, with specific reference to lightning. Other features that are related to specific local conditions but are worth mentioning are resistance to bird attack (a problem raised by Australian utilities) and the resistance to vandalism by shotgun attack.

Question 4.4: Ground cable, i.e. a cable suitable for placing underground

37 respondents state that this solution is or will be taken into consideration. However replies on specific features vary from one respondent to another.

A large majority (30) require the cable to be all insulating, while 17 require the cable to have conducting barrier protection, and 16 require the cable to be designed for direct bury. As regards co-existence of the cable with other armoured cables in the same duct, almost all the respondents (31) give this requirement.

It may be noted, however, that only seven respondents require the cable to have all of the characteristics at the same time i.e to be insulated, to have conducting barrier protection, to be designed for direct bury, and to co-exist with other armoured cables in the same duct.

The main concern seems to be the protection against attack by rodents and water infiltration. In the case of co-existence with other cables, emphasis is placed on withstand in respect of mechanical forces originated by the latter.

5. ENVIRONMENTAL CONSIDERATIONS

Question 5.1: Is the terminal equipment supplied to you especially engineered to allow it to be operated in an hostile electrical environment?

The terminal equipment supplied to utilities was specifically designed to operate in a hostile electrical environment (eg in substations, in switchyards, on towers etc.) in 20 cases (59%) and was not in 14 cases (41%).

Question 5.2: What range of climatic conditions has to be accommodated by the various components of your system?

The question was divided into three categories by various components: Cables, Terminal equipment and Regenerators. The minimum, average and maximum has been derived from the given environmental data.

	Cables	Terminal Equipment	Regenerators
Temperature (°C)			
- average (low, high)	-20, +55	0, +46	-5, +48
- minimum	-50	-20	-40
- maximum	+85	+70	+60
Humidity (%)			
- average	98	90	98
- minimum (upper bound)	80	60	80
- maximum	100	100	100
Wind speed (km/h)			
- average	147	-	120
- minimum (upper bound)	100	-	86
- maximum	220	-	144
Ice load (mm)			
- average	14	-	-
- minimum (upper bound)	6	-	-
- maximum	120	-	-
Solar radiation (W/m)			
- average	1170	-	-

Figure 5.1 shows the temperature ranges for cables as given by the utilities. (Fig 8.1 shows the same diagram with values given by the manufacturers). Utility side has given the lowest (-50 °C) and the highest (+85 °C) bound.

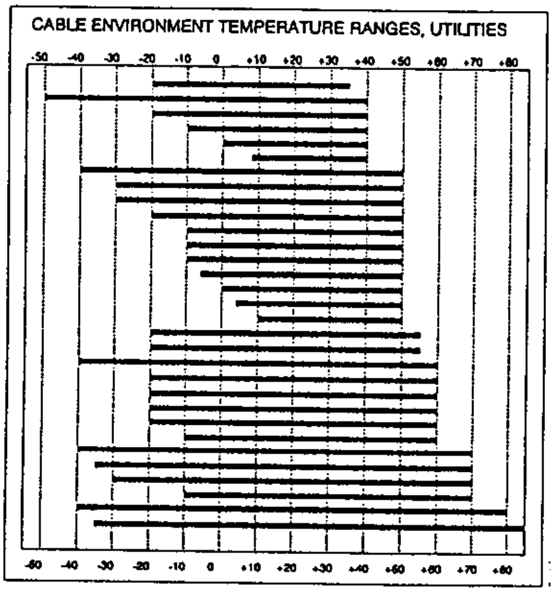

Figure 5.1: Environment temperature ranges for cables given by utilities

Salt corrosion was considered in 4 papers, VDE standard was mentioned (cables) and IEC standard (equipment, regenerators).

Water corrosion was considered in 4 papers, VDE standard was mentioned (cables) and IEC standard (equipment, regenerators).

Acid corrosion was considered in 3 papers, VDE standard was mentioned (cables) and IEC standard (equipment, regenerators).

The effects of sand were considered in 2 papers, VDE standard was mentioned (cables) and IEC standard (equipment, regenerators).

One non-halogenic, MIL-quality system was mentioned.

Question 5.3: What special protection is provided against..

.. Vandalism?

Locked buildings and fences for equipment and repeaters, alarm systems (motion detectors). Joint boxes installed >2 m above the ground.

Protection against vandalism was considered in 21 questionnaires of which 13 had used some protection.

.. Rodents?

Metallic and plastic conduits and ducts were used in installation and protective sheaths, nylon clads and metallic armouring in cable construction.

Protection against rodents was considered in 22 questionnaires and of which 15 use some protection.

.. Other animals?

Metallic conduits and ducts are used in installation. OPGW was used to avoid attack by birds. Nylon clad against termites.

Protection against other animals was considered in 28 questionnaires of which 6 had used some protection.

Question 5.4: What special mechanical considerations are incorporated into the equipment to protect the system against..

.. Vibration?

Dampers were used. Protection against vibration was considered in 15 questionnaires and in 8 cases some protection was used.

.. **Earthquake?**

Equipment tolerance and mounting techniques. Protection against earthquake was considered in 14 questionnaires and in 2 cases some protection was used.

.. **Falling trees?**

Protection as for normal conductors. Protection against falling trees was considered in 13 questionnaires and in 3 cases some protection was used.

.. **Lightning?**

Twin earth wires and surge arrestors were used. Protection against lightning was considered in 15 questionnaires and in 10 cases some protection was used.

6. MAINTENANCE OF PRESENT AND FUTURE SYSTEMS

Only 60% of the utilities' answered the questions on maintenance.

Some of the utilities have no experience and cannot answer this part of the questionnaire. Other important users answered "no comment" or "Data not available". The percentage corresponds with the effective answers.

Question 6.1: Who maintains the fibre optic cables used on your systems?

One fifth of the utilities answering the questionnaire use personnel from other firms (cable manufacturers) to maintain the fibre optic cables, which may indicate their concern for this new communication media.

Question 6.2: Who will maintain future fibre optic cable installations?

See question 6.1.

Question 6.3: Who maintains the fibre optic terminal/regenerator equipment used on your systems?

Generally the company personnel maintains fibre optic equipments on present or future systems.

Question 6.4: Who will maintain fibre optic terminal/regenerator equipment on your future systems?

See question 6.3.

Question 6.5: What type of commissioning measurements are carried out on new fibre optic cable installations?

About 50% of the utilities say that they use an OTDR for the evaluation of new fibre optic cables. Other companies require an end-to-end power loss measurement which may require the use of fibre cut back to obtain a true power measurement.

Question 6.6: What type of routine maintenance measurements (and at what frequency) are carried out on existing fibre optic cable installations?

This question has been answered by 58% of the respondents.

One third of the companies consider that no maintenance of fibre optic systems is required and are satisfied with terminal equipment alarms.

A second third of the companies is considering routine maintenance on an annual frequency and 5 % on a shorter frequency, especially during the first year. The other utilities have not yet made their choice.

Question 6.9: What type of link or network management is used to identify early or impending failure? Is there any remotely controlled reconfiguration capability?

One tenth of the companies have (or plan to have) a dynamic network with remotely controlled reconfiguration capability in case of impending failure.

This reconfiguration is mostly made by equipment redundancy.

Question 6.11: What is the planned return-to-service time of your systems in the event of a failure? What provisions are made to ensure that the planned return-to-service time is maintained?

This question was answered in 55 % of the questionnaires.

The mean time to repair (MTTR) is an important criterion for every user. However 45% did not give any figure and 6% recommend "a time as short as possible".

The others expect:

- MTTR < 6 hours	18%
- 6 hours < MTTR < 12 hours	15%
- 12 hours < MTTR	10%

The answers are quite different and show either a poor knowledge of this problem or that the question was misunderstood.

7. COMMERCIAL AND LEGAL CONSIDERATIONS

Question 7.1: What economic considerations are taken into account when planning new fibre optic systems?

In general the economic considerations taken into account when planning new fibre optic systems are:

1) What length of time will pass before there is a return on the capital investment and maintenance costs concerned with operating a fibre optic system.

2) What is the competitiveness of conventional telecomms systems against fibre optic systems (i.e. microwave radio).

Other considerations need to be given to using groundwires, buried and overhead cable and their prices compared. Some consideration may also be given to security of communication.

It can be noted, that some companies take technical considerations as the main criteria overriding economical consideration.

Question 7.2: What other telecommunications systems are considered before a fibre optic solution?

The other forms of telecommunications systems considered are mostly UHF/microwave radio applications. However, some PLC and PTT services are also taken into account.

Question 7.3: What are the link distances where new fibre optic systems provide a more economic solution to other types of new transmission systems?

When carrying out economical surveys the main things considered by companies are: existing power line routes, equipment and installation costs, capacity and terrain.

From the returned questionnaires the overall economic breakpoint appears to be approximately 16 km.

Question 7.4: What other types of existing communication systems are being replaced by new fibre optic systems?

The table below shows the general trend for existing communications links being planned by those who respond to this part of the questionnaire.

Type of system to be replaced	Date of replacement	System capacity	Number of systems
Microwave	1989	283 channels	31
PLC	1990	34 channels	4..5
PTT links	1990	88 channels	28

It should be noted that the date of replacement, system capacity and the number of systems are all mean values calculated from the results given by the companies who have provided answers for each system type.

Question 7.5: Are you considering any joint venture fibre optic systems with a third party?

In general 35% of companies who replied are indicating that they would consider joint ventures in fibre optic systems with a third party.

Question 7.6: If you are considering joint ventures as in 7.5 above how will the system be shared?

In general 30% of companies who say they would consider joint ventures would opt for separate fibre in a common cable.

Question 7.7: Who will own the cables and terminal equipment that carry your own services in any joint venture scheme?

The joint venture may be owned as a whole or by individual share holders.

Question 7.8: Who will maintain the cables and terminal equipment that carry your own services in any joint venture scheme?

Amongst the answering utilities seven maintain the whole installation by their own staff; in three cases maintenance is carried out by the supplier.

In addition, the following special solutions are given:

- The aerial cable is maintained by the utility, the buried one by the PTT:

- The cable is maintained by the utility as cable owner; the individual fibres plus corresponding terminal equipment are owned and maintained by the different users.

- The cable is installed and maintained by the underground railway company, the terminal equipment maintained by the users.

Question 7.9: Do you intend to create a new business idea by renting fibre optic services to external users?

20% of companies say they would create a new business by renting fibre optic services to external users.

Question 7.10: Are there any legal restrictions on the type of traffic carried or particular interconnections made to other systems on private utility owned communication links?

About half the companies involved say legal restrictions will play a part.

8. MANUFACTURERS

Question 8.1.1 - 8.1.3: Size and origin of the company?

Questionnaire was returned by 15 manufacturers of varying sizes. Smallest company employed 14 and biggest 310 000? Five of the companies were from United Kingdom, five from Japan, two from West Germany and one from Denmark, Finland and Italy.

8.2 Standards

Question 8.2: What international or national standards do you use when specifying fibre optic systems?

International and national standards and recommendations were used by manufacturers specifying fibre optic systems as follows (see glossary of terms):

- CCITT recommendations G651 and G652
- IEC specifications (793-2, 794-1)
- ASTM specifications
- DIN/VDE specifications
- British standards, British telecom specifications
- IEEE
- JIS, JCA, EIA
- SFS

8.3 Cable technology for future optic systems

Question 8.3.1: Composite conductor (fibres embedded within the conductor)

Two of the companies manufacture phase wire composite conductor covering voltage range from 20 to 400 kV. Nine of the companies manufacture earth wire composite conductor for line routes whose voltages are up to 1050 kV.

Single mode, multi mode or both types of fibres were used in constructions. Loose tube bufferings with SM fibres was the most common type. The fibre count in loose tube construction was up to 24 and in tight buffered type up to 30.

Both aluminium clad steel and aluminium alloy strands were used in the armouring of loose tube composite conductors. In tight buffered constructions only aluminium clad steel was used to prevent elongation of the cable.

Question 8.3.2: Self supporting aerial cable?

Eight of the manufacturers provide all insulating, four semi-conducting and seven conducting construction.

Span lengths were up to 1000 meters also with non-metallic construction. Maximum sag varied from 2.7 m to 42 m. Maximum working tension varied from 22.5 kN to 220 kN.

SM and MM fibres were available for wave lengths 1300 nm and 1550 nm up to 24 fibres per cable. Only loose tube design was mentioned (giving zero longitudinal fibre strain). Fibre Reinforced Plastic (FRP) and Kevlar were mentioned as the supporting element material in all-insulating cables.

Question 8.3.3: Attached cable (attached to an existing conductor)?

Three manufacturers provide wrapping type cable for earth wire and one also for phase wire. One manufacturer mentioned that suitable voltage range would be 0 - 150 kV. Two manufacturers provide clipping type cables for earth conductor and one also for phase conductor. One manufacturer claimed that the reliability of the wrapping and clipping type cables is poor compared to OPGW and that is the reason why he does not manufacture these types.

Question 8.3.4: Ground cable

Eight manufacturers provide all-insulating ground cable, ten with conductive barrier. Nine of the manufacturers have a cable to be buried directly to the ground and ten said that their cable can co-exist with other metallic cables.

Cables are mainly water tight and incorporate metallic or kevlar rodent protection.

8.4 Environmental considerations

Question 8.4.1: What range of climatic conditions has to be accommodated by the various components of your cable system?

Environment temperature range for **cables** varied from lower bound -45 °C to upper bound +70 °C. Average lower bound was -32 °C and average upper bound +60 °C.

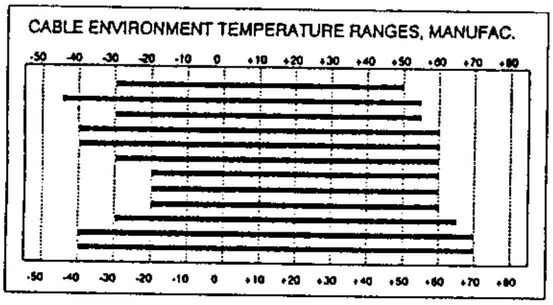

Figure 8.1: Environmental temperature ranges for cables given by manufacturers.

A comparison of lower and upper temperature limits given by utilities (see chapter 5) with the limits given by manufacturers is made in figure 8.2.

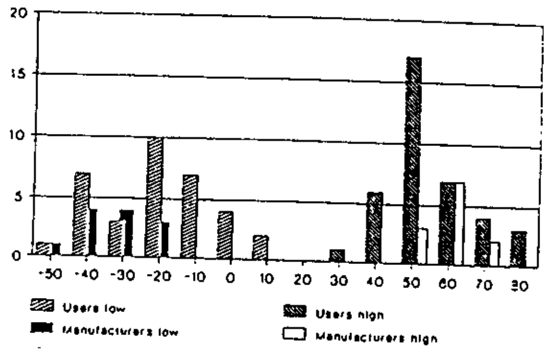

Figure 8.2: Number of answering utilities and manufacturers giving lower and upper limits of cable environment temperature ranges

Allowed humidity was up to 100% for cables and accessories.

Allowed wind speed varied from 22 m/s to 40 m/s. Average allowed wind speed for cables was 32 m/s.

Allowed ice load varied from 5 mm to 25 mm radius. Average ice load (=design value) was 11.5 mm radius. This value varies from country to country depending on the national standards.

Some provided their cables for any solar conditions and some had designed their cables for radiation of 1000 W/m.

Two manufacturers had considered salt corrosion and they used the IEC 507 as a design basis.

Question 8.4.2: What special protection is provided against vandalism and rodents?

The fibre optic systems were protected against vandalism by using protective shields (armouring, steel tape) and by placing the joint boxes at a high location.

Against rodents metallic shields, kevlar and nylon were used.

Question 8.4.3: What special electrical and mechanical considerations are incorporated into the cables and accessories to protect against vibration, earthquake, falling trees, lightning strikes etc?

Against vibration dampers and filled cables were used. One manufacturer claimed that large diameter reduces vibration?

Against earthquakes no special precautions were made or just high mechanical strength was mentioned.

Against falling trees the overall mechanical strength was mentioned.

Against lightning non-metallic cable, protective coating for fibres and high resistivity were mentioned.

8.5. Maintenance of present and future cable systems

Question 8.5.1 and 8.5.2: Who maintains the fibre optic cables supplied by your company (present and in future)

In three cases the manufacturer maintains the installed fibre optic cable and in two cases either manufacturer or owner of the line takes care of the maintenance. In eight cases customer maintains the cable.

In future cable installations the same practice as present will be continued. Maintaining the terminal and regenerator equipment will be taken care of either by the equipment supplier or the customer for both the present and future installations.

In commissioning usually OTDR (optical time domain reflectometer, back scattering) and power measurements will be done. One manufacturer claims also to make a dispersion measurement.

Routine tests are mainly done by the customer. OTDR is the most common measurement.

Planned return to service time varied depending on the damage and customer from 24 hours to one week.

9. REFERENCES

[1] CIGRÉ Study Committee 35: Telecommunications Statistics, June 1988

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Published by CIGRE
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