CEOCOR

Comitè d’Etude de la Corrosion et de la Protection des Canalisations

AC CORROSION ON CATHODICALLY PROTECTED PIPELINES

Guidelines for risk assessment and mitigation measures

ANNEX N. 2

CORROSION DUE TO ALTERNATING CURRENT ON METALLIC BURIED PIPELINES: BACKGROUND AND PERSPECTIVES

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Association for protection
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CORROSION DUE TO ALTERNATING CURRENT ON METALLIC BURIED PIPELINES: BACKGROUND AND PERSPECTIVES

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Synopsis

This document illustrates the real extent of the risks of corrosion due to alternating currents and gives useful ideas for minimising these risks in the simplest, least conflictual and most economic way. It also highlights the need for collaboration and operational co-ordination between the system manager (operator) which creates interference and the manager (operator) of the metallic buried pipelines.
The reasons behind the spread of corrosive phenomenon and their growing importance in recent years are illustrated.
Some examples of corrosion due to alternating current and their parameters are reported, on the basis of which their typical characteristics can be defined.
The operational consequences for the manager (operator) of the metallic buried pipelines and the existing and potential agreements between the various operators are looked at.
Current European research in this field is described.

Summary

The influence of alternating currents on metallic buried structures is well known in Europe; it is important for the safety of personnel and plant and for the cathodic protection of metallic buried structures against corrosion.
The most common cause derives from the installation of power lines with increasingly high tension and power , and high speed traction systems powered by alternating current.
Factors that increase the presence of AC tension on the metallic buried structures and pipelines include:

- improvements in materials used for pipeline coating (e.g. three-layer polyethylene);

- verification of coating integrity when pipeline laying;

- more power lines, higher nominal tension and higher power;

- geological reasons behind parallel runs, creating increasingly crowded services channels.

To ensure the safety of people working on the metallic buried structures and to enable buried structures to be monitored for cathodic protection, a design with suitable protection devices should be taken into account from the start of pipeline laying. The effectiveness of the protection devices should be verified with periodic maintenance operations.
For such end and in the mutual interest of the managers of the structures, the exchange of information and the co-ordination of activities, both planning and operational, are fundamental.
Legal requirements and technical standards are becoming increasing In Denmark, Norway and Sweden protocol agreements between the electricity utilities and the metallic buried structure manager (e.g. gas company) have been drawn up. These are illustrated.
In this document the corrosive effects of the alternating current on buried metallic structures, its background and the common studies and search programs in Europe are taken into account.

1- Presence of alternating current on the metallic buried structure

Corrosion due to alternating current on metallic buried pipelines was for many years not considered very important by corrosion experts nor cathodic protection experts.

This was because:

- the electrochemical phenomena of corrosion are normally attributed to direct current;

- the instruments normally used to measure the electric parameters in direct currents can't correctly detect the presence of AC current with frequencies between 50 and 100 Hz.

Till now, the corrosive effect of alternating current on metallic buried pipelines has been considered small or non-existent because with old type coatings (e.g. bitumen) pipeline electrical isolation values are rather low.
This type of coating is made of porous materials and in the presence of crossing or extensive parallelisms with high voltage electric lines the induced tension on the metallic buried structure is attenuated by the presence of this porosity which creates a uniform dispersion of the alternating current from the pipe to the earth.
The pipe to soil potential measured in these conditions is normally low, (i.e. a few volts), and the current density with such a uniform porosity is negligible.
However, doubts on the corrosive effect of alternating current are due to the fact that the short duration (10 ms) of the alternating current's positive curve renders it insufficient to modify the polarisation state of the structure surface in contact with the soil due to the cathodic protection current.
In reality, as we will see , while the corrosive effects of alternating currents are no longer in doubt, the mechanisms behind the phenomenon have not yet been completely established.
Coating defects could be found with presence of a high density of ac current and a high density of cathodic protection current too; this fact has tended to draw attention away from the possibility of corrosion deriving from alternating current.
The pipe to soil potential measured in these conditions (effective resultant value from the sum of the direct current and the induced alternating current) are normally sufficiently negative relative to the criteria commonly used for the cathodic protection criteria.
With the advent of the new generation of coatings (e.g. three-layer polyethylene) pipeline electrical isolation values have become very high (e.g. 5000- 50000 ohm.m² for bitumen and 300000-1000000 ohm.m²).
For the last 4 or 5 years the coating defect survey has been increasingly carried out immediately after pipeline laying and hydraulic testing.
In order to ensure good quality control of the coating, the cost of eventual excavation and repair should be the responsibility of the construction company.

Corrosion due to alternating is aggravated by:

- the use of higher quality and defect-free coating produces higher induced tension on the pipeline;

- a higher probability that, from the remaining small coating defects, a higher density of AC current could come to the soil.

In reality, before the use of the new type of coating, corrosion due to alternating current was found on pipelines also with the old type of coating.

2. Corrosion due to alternating current

2.1. Corrosion cases

Cases of corrosion in Switzerland and Germany since 1986 from alternating current of 162/ 3 Hz and 50 Hz have been compared. In all of those cases, the pipe to soil potential measured conformed to cathodic protection criteria with negative values greater than -0,850 mV measured by the Cu-$CuSO_4$ electrode.
On the basis of European experience it seems that it is likely that some cases of corrosion due to alternating current have not been recognised as such.
Only recently GERG (European Gas Research Group) studies have identified the parameters which, if taken together, indicate that corrosion is due to alternating current.
GERG is an organisation of experts from different sectors (pipelines for gas transport companies) in Joint Research Project Teams working on research problems of common interest.
The following cases of corrosion are clearly due to alternating current:

Case 1

Pipeline	DN pipeline 500 mm
Coating:	2 layer polyethylene
Type of soil:	Sand/ slime
Resistivity:	35 Ohm.m
Soil resistivity (near the corrosion):	2 Ohm.m
pH of the soil (near the corrosion):	13- 14
Parallelism of 4 km with electric line:	80 kV- 16 2/ 3 Hz
Time of exposure:	25 years
Position:	narrow parallelism
Voff potential:	- 950 mV
Average alternating value measured:	30 V rms
Corrosion survey:	intensive potential measures
Corrosion products:	also magnetite

Case 2

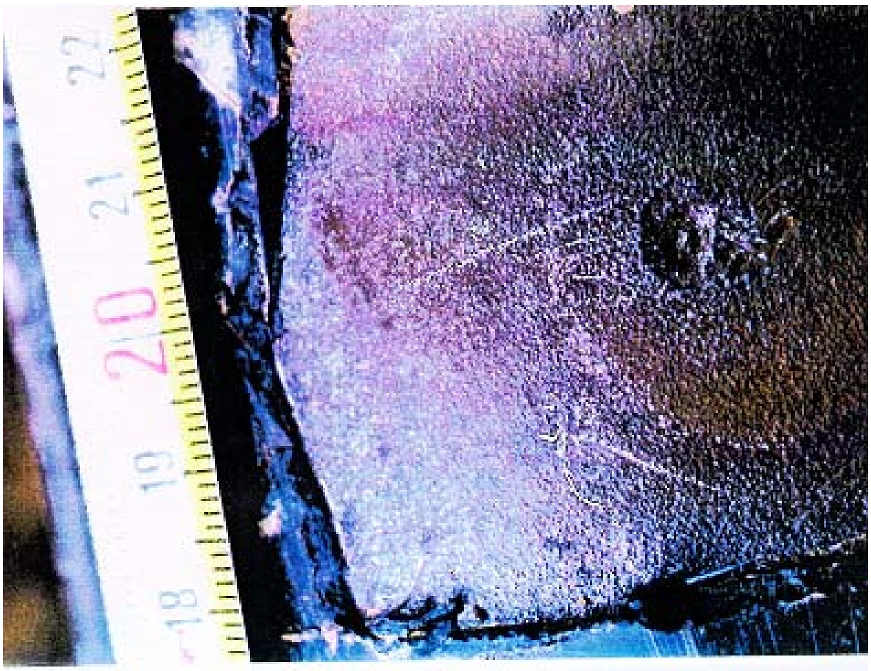
Pipeline	DN pipeline 500 mm
Coating:	Bitumen
Type of soil:	Sand/ slime
Resistivity:	35 Ohm.m
Soil resistivity (near corrosion):	2 Ohm.m
pH of the soil (near the corrosion):	13- 14
Parallelism of 4 km with electric line:	380 kV- 50 Hz
Time of exposure:	20 years
Position:	narrow parallelism
Voff potential:	- 950 mV
Average alternating value measured:	30 V rms
Corrosion survey:	pigging

Note: formation of stalactite on the soil

Case 3

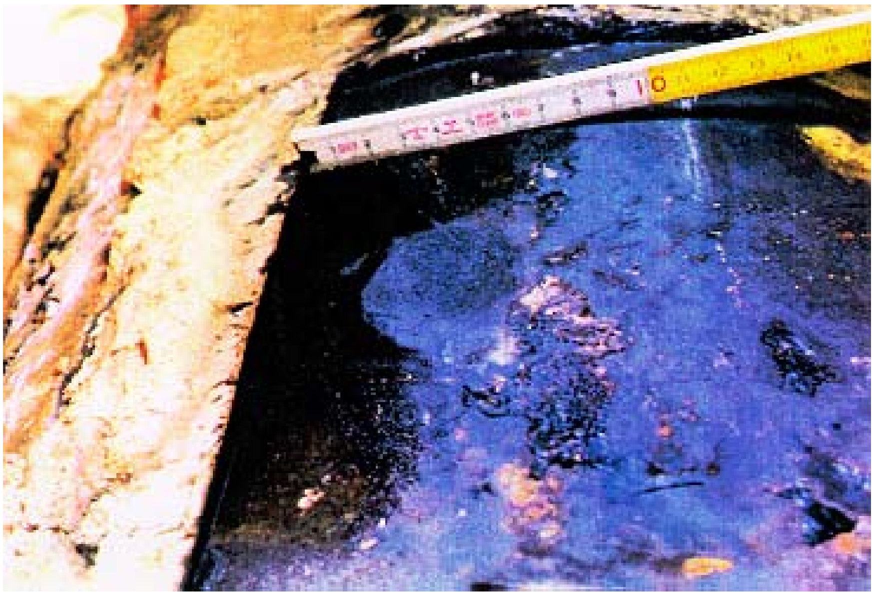
Pipeline	DN pipeline 100 mm
Coating:	Polyethylene
Type of soil:	clay
Resistivity:	20 - 300 Ohm.m
Soil resistivity (near corrosion):	2 Ohm.m
pH of the soil (near the corrosion):	12
Parallelism of 2,5 km with electric line:	380 kV- 50 Hz
Time of exposure:	1 years
Position:	along the pipeline
Voff potential:	- 950 mV
Average alternating value measured:	13 V rms
Corrosion survey:	coating defect survey

Note: Presence of 31 defects in 1.5 km . N. 20 of these defects, corrosions have been found with surfaces from 4 to 300 mm^2



Case 4

Pipeline	DN pipeline 100 mm
Coating:	Bitumen
Type of soil:	Sand/ slime
Resistivity:	35 Ohm.m
Soil resistivity (near corrosion):	2 Ohm.m
pH of the soil (near the corrosion):	13 - 14
Parallelism of 4 km with electric line:	380 kV- 50 Hz
Time of exposure:	20 years
Position:	narrow parallelism
Voff potential:	- 950 mV
Average alternating value measured:	30 V rms
Corrosion survey:	pigging



Case 5

Pipeline	DN pipeline 200 mm
Coating:	Bitumen and polyethylene for repairing
Type of soil:	Sand/ slime
Resistivity:	3 Ohm.m
Soil resistivity (near the corrosion):	0,6 Ohm.m
pH of the soil (near the corrosion):	-------------
Parallelism of 4 km with electric line:	120 kV- 50 Hz
Time of exposure:	11 years
Position:	parallelism near substation
Voff potential:	- 1000 mV
Average alternating value measured:	14,5 V rms
Corrosion survey:	electric measurements

2.2. - Characterisation of a corrosion due to alternating current

In the corrosion field it is fundamental to ascertain the causes of corrosive phenomena.
This may be done by measurement in situ or by using samples that can subsequently be analysed in the laboratory.
In the cases of corrosion due to alternating current this type of failure - analysis is particularly important, especially for parameters to be measured in the field.
In the GERG study on "AC Corrosion" a protocol of analysis was prepared which is up-datable in the light of new information.
This analysis protocol could be used for characterising this type of phenomenon.

The characteristics of corrosion due to alternating current are the following:

- presence of AC voltage on the pipeline;
- presence of a defect in the coating (usually an open small defect);
- presence of corrosion;
- protection voltage on the pipeline (negative Voff potential greater than -850 mV related to Cu-$CuSO_4$);
- elevated pH values of the soil in the vicinity of the corrosion (pH >10) – microbial corrosion usually shows pH values of 3 – 5, also due to lack of cathodic protection current;
- the corrosion form is usually rounded, similar to the cast of a sphere;
- the corroded area is larger than the coating defect ;
- corrosion products are very bulky and could be removed as a bloc;
- after the clearance of corrosion products, thin magnetite film could be present on the metal surface;
- very high AC and DC densities;
- very low soil resistivity, especially in the vicinity of the defect;
- presence of substantial disbonding of the coating relative to the dimensions of the corrosion;
- presence on the corrosion surface or in the vicinity of corrosion of a large quantity of calcium carbonate;
- presence of magnetite within corrosion products;
- presence of a formation of soil like a stalactite.

If most of those characteristic are found together, the probability of corrosion due to alternating current is very high.

3- background of the corrosion due to alternating current on metallic buried pipeline.

In order to estimate the risk of corrosion due to alternating current present on a metallic buried pipeline, the following considerations should be taken into account:

- a lower IR free potential value than the cathodic protection value means that the effectiveness of the cathodic protection can not be demonstrated if at the same time there is the presence of an AC current density of more than a few tens of A/m^2;

- the chemical composition and resistivity of the soil have a strong influence on the corrosion rate; soil with CaCO3 and CO2 increases the corrosion rate;

- laboratory tests show us that an increased current of cathodic protection could have an increase of the corrosion rate due to alternating current;

- the risk of corrosion is higher on pipelines with a higher insulating resistance values and in the presence of small defects (a few cm2);

- *The following questions should be taken into account:*

  * *fixed influence in space but varying in intensity and in time, in the presence of power transmission lines ;*

  * *varying influence in space and time for traction systems powered with AC.*

- *In determinating the risk of corrosion, how to identify the different variables when they occur contemporaneously?*

While the most easily measured parameter is the pipe to soil potential, the effect of AC corrosion is due to the density of current changed between the exposed steel and the soil.

- *How to measure values of current density?*

  * dimension of probes
  * their positioning
  * type of instruments for the measure of the AC and DC values .

While for density of current to 30 A/m2 the corrosive effect exists for any type of soil, for density of current 20 - 30 A/m2 it is only in the presence of particular types of soil.

- *How to evaluate the corrosive effect for these conditions?*

Tests in the laboratory and in the field highlight an effect of "incubation" of the alternating current before reaching values of current density that give rise to corrosive phenomena.

Studies and researches at European level are in course in order to evaluate these phenomena.

4 - Operational consequences for the managers of buried pipelines

Due to possible corrosion risk, in the case of crossings and/ or parallelisms with high voltage power lines or traction systems powered with AC, operators should consider taking precautionary measures.
In particular:

- the presence of small/very small coating faults, which were once considered easy to cathodically protect against corrosion, may represent a major corrosion risk;

- for the zones where the influence of AC is possible, the management should consider including in the maintenance plans also the systematic measurement of AC pipe to soil measurements and relevant values of current density, eventually by introducing installation and use of proper probes. Since the characteristics of induced AC voltages on pipelines may be noticeably variable in time, long term recording of such values are necessary;

- it will be necessary to up date the electrical schemes of the pipeline network including in the plans the position of the electric power lines parallel to the pipelines.

We underline that the influences due to alternating current are variable; this variability is tied to the operating load, seasonal variations of power consumption, maintenance needs and the operational variations of the systems for transportation of energy.
Hence the need for the operator to be aware, as soon as possible, of the installation of new systems, or operational modifications.
An example for realising this is the agreement between the Energy of Electric Danish Association and the Companies managing buried pipelines in Denmark, whose aim is to deal with problems of "Proximity between high voltage power line and buried pipelines."
The text of this agreement is shown in the Attachment 1.
Other information on this matter is furnished in this text; presented during the CEOCOR Conference of Prague in December, 1995.
In Germany, the Federal Railroads take on part of the costs necessary to modify the installations for attenuating AC interference on pipelines.
In Norway legal actions have been started by some operators of buried pipelines concerning AC corrosions caused by electricity lines.
In France an agreement has been set up some years ago between the main users of the sub-soil electric systems (SNCF, P& T, EDF/ GDF and others). This agreement requires each user to be responsible for the measures to be taken in respect to its own structures while the operator responsible for the electrical influences provides the finance, when necessary, for the installation of the devices needed to solve the problems.
It has been noted that setting up an agreement like this is much less onerous than taking legal action, which may be time consuming, expensive and still not solve the real problem.

5 – Research in course in Europe

5.1. Field research

In GERG (European Gas Research Group), since 1992 a common research project on this matter has been underway, with the participation of numerous European gas transport companies (Snam, Ruhrgas, British Gas, Distrigas, Gaz de France, Enagas, Gasunie, Dong).

A project specification has been agreed upon with the following purposes:

- to jointly develop and evaluate protective measures on pipelines influenced by high voltage electric lines or from traction systems powered with AC;

- to reach a consensus of opinion and understanding of the subject.

To reach these objectives, the following activities have been scheduled:

- exchange of experience of AC corrosion cases, on the instrumentation, the measurement techniques, the tools and the criteria to control induced AC voltage and its corrosive effects on buried pipelines;

- comparison of computer programs for calculating the influence of AC in case of parallelisms and intersections between pipelines and high voltage power pipelines, which should be able to take into account the inductive, resistive and capacitive effects;

- execution of tests and measurements in the field with the subsequent exchange and discussion of the results.

The fundamental objectives of this Joint Research Group are the following:

- to evaluate and quantify measurable parameters in the field that can predict the existence of a corrosion risk on buried pipelines;

- to define interventions able to mitigate induced voltages on the pipelines to such levels as avoid or minimise the risk of corrosion;

- to furnish an updated technical support to facilitate the normative work for European standardisation on this matter (CEN TC 262).

Field activities of this Joint Research Group will finish in July 1997.
Beyond the execution of measurements on real pipelines, within this project two types of probes have been defined that will be jointly used:

- probes for AC corrosion measurements;
- probes for AC voltage and current measurements.

5.2. Research in the laboratory

To reach the objective of the project, the companies which take part in this research group have declared their support of the costs of laboratory research to clarify the electrochemical mechanisms of AC corrosion and, more importantly, to define the parameters to be detected with standard measurements (field measurements) for ascertaining or excluding a "risk of corrosion" due to the presence of alternating current on the pipelines.

For the GERG laboratory activities the specification and program of the project are in course of definition. Laboratory tests have the following fundamental objectives:

- understanding of the mechanisms for the formation/destruction of the polarisation film while DC current from Cathodic Protection Feeders and AC current are contemporaneously present;

- behaviour of this polarisation film when changing AC/DC ratios;

- defining which measurements (DC and AC) are to be performed at the soil surface above a pipeline for ascertaining a risk of corrosion.

5.3. - Acquisition of computer programs

Within this GERG research some evaluations are being made on existing computer programs for the inductive, capacitive and resistive effects of alternating current.
RWE, a German company, presented a computer program (in German) that is able to take into account the different kind of influence couplings; this is an updated version of a computer program normally used by Ruhrgas, British Gas and Dong.

GERG members asked RWE to furnish an English version of this program able to acquire the data relevant to the parallelisms by automatic input of the geographical co-ordinates of electric systems and pipelines.
If the results of the program prove reliable, it will be made available for use at European level and therefore also in Italy.

ATTACHMENT 1

Agreement between gas and power companies

28/02/1996

Agreement
between

Danske Elværkers Forening	-	The Association of Danish Electric Utilities
and		
Dansk Olie og Naturgas A/S	-	The National Oil and Gas Company of Denmark
Hovedstadens Naturgas Selskab I/S	-	The greater Copenhagen Area Distribution Company
Naturgas Sjælland I/S	-	The Regional Gas Company of Zealand
Naturgas Fyn I/S	-	The Regional Gas Company of Funen
Naturgas Midt/Nord I/S	-	The Regional Gas Company of Mid and North Jutland
Naturgas Syd I/S	-	The Regional Gas Company of South Jutland

Concerning proximity between high-voltage systems and metallic pipe systems

List of Contents:

Section 1: Purpose, definitions

1.1 Purpose

Upon proximity between high-voltage systems and metallic pipe systems the purpose of this agreement is:

- to ensure observance of the provisions of the "High-Voltage Regulations";
- to ensure implementation of necessary insulating measures;
- to lay down directions as to who will prompt and pay the costs of the implementation of the mentioned safety and insulating measures;
- to lay down directions as to who shall operate and maintain the above safety and insulating measures as well as pay for the expenses involved.

1.2 Definitions

The definitions adopted are stated in the Handbook of Proximity between gas and electric systems (dated 1 May 1993) in the following referred to as "the Handbook".

Section 2: Co-operation, etc.

2.1 Daily co-operation

The daily co-operation concerning proximity matters is a direct co-operation between the parties involved. (Cf. S. 4.8).

2.2 The Proximity Committee

The Proximity Committee deals with general proximity matters. Both parties are represented in the Proximity Committee.

2.3 Preparation of material

The methods of calculation used are stated in the Handbook.

The parties cooperate on producing and updating the technical methods of calculation mentioned.

2.4 Duty to inform

2.4.1. According to the agreement the parties involved are obliged to inform each other of future planned line systems, changes of existing systems or operational changes.

The parties shall inform each other in good time to make it possible to carry out the safety and insulating measures necessary before new systems are put into operation and/or there are operational changes of existing systems.

Once a year a meeting is held where information is exchanged according to agreement between the parties. Minutes of meeting shall be prepared.

2.4.2 When it has been decided to build metallic pipe systems the gas companies are obliged to immediately contact the power company/ies concerned.

2.4.3 When it has been decided to build high-voltage systems the power companies are obliged to immediately inform the gas company/ies concerned.

2.4.4. The parties mentioned are obliged to present the information necessary for a survey of proximity effects.

Section 3 Technical conditions

3.1 Planning and calculation

Whether a proximity effect exists which will lead to implementation of permanent measures is decided on the basis of calculations and potential measurements in accordance with the directions of the Handbook.

3.2 Preliminary survey

3.2.1 A calculation basis and the carrying out of calculations or of potential measurements must be carried out as quickly as possible and must not cause unnecessary delays for the party who wishes to establish new systems or change the operation of existing systems.

3.2.2 When carrying out proximity calculations at preliminary surveys and the project phase the DONG owned computer program is placed at the disposal of the parties free of charge. Further Dansk Olie og Naturgas A/S has undertaken to update the program upon mutual decision between the contracting parties.

If more recent or improved programs are produced the parties will consider whether to use these programs instead. The programs shall then be purchased by Dansk Olie og Naturgas A/S.

3.3 Projecting and construction

3.3.1 If it is required on the basis of the calculations or measurements carried out to set up proximity measures the parties involved shall make the decisions necessary for the measures to be carried out before new systems or operational changes of existing systems are put into operation.

3.3.2 The parties agree that the measures with the lowest costs for the parties involved should be chosen no matter where the measures are to be established.

3.3.3 The measures the parties agree to be implemented by the owner of the installation where the measures are to be established.

3.4 Commissioning and control measurements

The time of commissioning must be agreed upon in each proximity matter.

Control measurements may upon agreement be carried out to ensure the ability to function of the safety and insulating measures as well as of the installations.

3.5 Operation and maintenance

Operation and maintenance of the safety and insulating measures rest with the party on whose system the measures are carried out.

3.6 Responsibility for the use of computer programs, data, etc.

The responsibility for any use of the program mentioned in S.3.2.2 rests exclusively with the executing company.

The parties involved are each on their part responsible for the correctness of the data they deliver for use for the calculations mentioned in S. 3.1

The responsibility for the assessment of the calculation results rests with the owners of the installations on which the safety and insulating measures are to be established.

Dansk Olie og Naturgas A/S is not responsible for the correctness of the program.

3.7 Means of Access

The parties shall to the extent practicable have access to the other party's installations. Access shall be made in a secure way as to safety and according to the regulations of the company in question and only according to agreement. A representative of the owner of the installation shall be present.

3.8 Documentation, etc.

Each party touched by proximity shall uphold records and as-built file for proximity matters.

Section 4: Economy

4.1 Planning

The power and gas companies are obliged to establish their installations in the most expedient way with a view to reducing the costs of present and future proximity matters.

4.2 Survey

Each party carries his own expenses for any kind of examination unless otherwise agreed.

4.3 Calculations

The calculations mentioned in S.3.1 are carried out by the power company/ies involved who shall also bear the expenses.

4.4 Projecting and construction

Costs concerning the agreed proximity measures including relevant project design is borne by the party whose installation has been planned or changed.

4.5 Operation and maintenance

Costs for operation and maintenance of the agreed proximity measures are borne by the party on whose installation the measures are established.

4.6 Other circumstances

Under extraordinary circumstances a different allocation of the costs may take place, e.g. in matters where the measures carried out entail essential advantages for the owner of the installations, where they are implemented or in case one of the parties involved e.g. uses techniques that are more sensitive to disturbances than so far used plant types.

4.7 Individual safety requirements and countering of injurious effects

Any measures that are not required according to S.3 may only be initiated for the account of the party concerned.

4.8 Agreement

For every proximity matter a written agreement between the parties involved is prepared containing the final, agreed specific measures, the allocation of the costs as well as the terms of payment and attached to this Agreement.

Section 5: Disputes

5.1 Negotiation

Should a dispute occur between on the one side the gas companies and on the other side a member of Danske Elværkers Forening concerning the interpretation of this agreement, its use under specific circumstances, or if the parties involved cannot agree upon such an agreement as mentioned in S.4.8 the parties involved must seek to remove the disagreement through negotiation.

5.2 The Proximity Committee

If the disagreement cannot be removed through negotiation, the question must be submitted to the Proximity Committee for reference with a view to an amicable settlement between the parties. If agreement has not been reached each of the parties involved may bring the matter before a Court of Arbitration.

5.3 Court of Arbitration

The Court of Arbitration shall consist of three arbitrators, of which the two must have sufficient technical knowledge while the third must be a judge or a former judge and be the umpire of the Court of Arbitration.

The party who starts the arbitration proceedings must inform the other party of his choice of arbitrator and request the opposition (the other party), within 14 days, to appoint his arbitrator. These two arbitrators shall then in unison appoint the umpire of the Court of Arbitration. If they

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are unable to agree upon this, or if the opposition fails to appoint his arbitrator, he/they is/are appointed by the President of the Maritime and Commercial Court in Copenhagen.

The ruling of the Court of Arbitration is final and cannot be brought before the courts.

Section 6: Changes

Each party of this agreement may call for a negotiation of conditions/matters that have not been anticipated in this agreement or in the Handbook.

Section 7: Termination

The parties in writing with one year's notice may terminate this agreement.

Section 8: Commencement

This agreement replaces the corresponding. agreement of 18 May 1981 and shall commence on 1 May 1993.