[Return to Session](#)

RE-EVALUATION OF 150 KV CABLE CAPACITY

Dirk VAN HOUWELINGEN, ENECO-Netbeheer, (Netherlands), d.vanhouwelingen@netbeheer.eneco.nl
Jos VAN ROSSUM, PRYSMIAN Cables & Systems B.V, (Netherlands), jos.rossum@prysmian.com

ABSTRACT

In asset management an update of asset data is necessary as circumstances change. In 2004 ENECO-Netbeheer and Prysmian cables and Systems BV re-evaluated the status and transport capacity of old 150 kV cables. This paper describes the results.
The status of the cables was acceptable.
As ground parameters change over time, these were determined along the cables again. Also a current profile and sheath temperature were measured during a month. A new calculation of the transport capacity using IEC60287 and IEC60853-2 resulted in a cyclic rating with a peak load of 56-109 % of the old rating.

KEYWORDS

150 kV cables, Condition assessment, Current rating, Transport capacity, Cyclic rating

INTRODUCTION

ENECO has used 150 kV cables for a long time, since 1961. The cables have aged and the surroundings have changed. To determine the right asset data for future grid development, a survey was started to find out the condition of cables and their surroundings, and to evaluate their present transport capacity.

HISTORY

In 1959 GEB-Rotterdam (now a part of ENECO) ordered its first 150 kV cable at NKF (now Prysmian). This cable is in operation since 1961 as part of a 150 kV circuit to supply energy to substation Botlek.

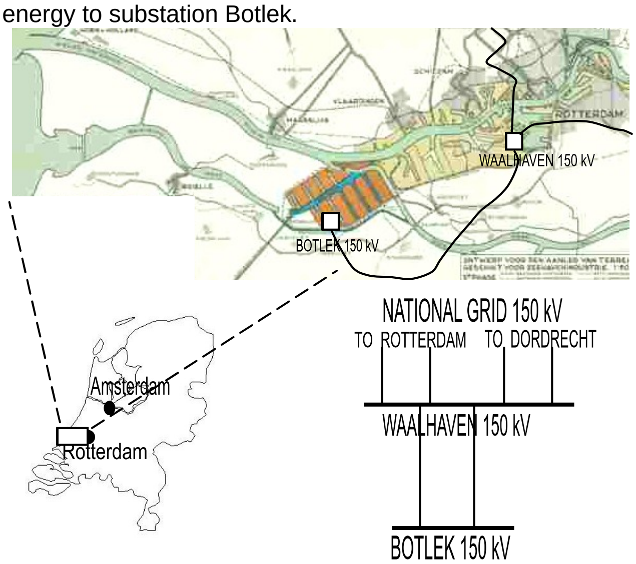

Figure 1: Planning map and grid structure 1961

During the sixties and seventies the Rotterdam harbour was growing rapidly. This resulted in a major extension of the grid. In this period more 150 kV cables and overhead lines were installed to supply electricity to the new harbour areas. The substations Europoort, Theemsweg, Oudeland and Maasvlakte were erected. Finally, around 1980 a 380 kV overhead line was completed between the national 380 kV grid and the Maasvlakte-area.
In the last two decades most of the growing energy need has been supplied by decentralized production in the area. Major expansions of the grid stopped, but several stations were built to connect the new power plants.
Also, the extension of roads and other infrastructures, led to reconstruction of existing cables and overhead lines.

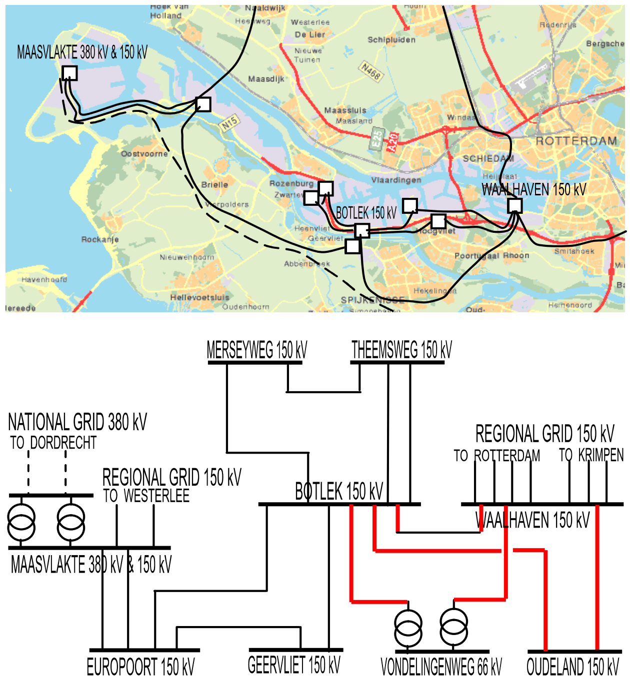

Figure 2: Map and grid structure 2000

As a result, the old cables are still functioning, but in a drastically altered surrounding.

OVERVIEW OF CIRCUITS

This paper deals with four 150 kV cable circuits, built from 1959 to 1969, that are still in use today. These are:

- o Waalhaven-Oudeland
- o Waalhaven-Botlek
- o Waalhaven-Vondelingenweg
- o Botlek-Oudeland

The 1994 Botlek-Vondelingenweg cable is included in the capacity calculations, it runs parallel to Botlek-Oudeland .

In figure 2 the five circuits are indicated in bold red lines.

Circuit	Conductor size	Isolation	Earting system	Year of production	Section length
Waalhaven-Oudeland section 1	800 mm2 Cu	Paper, l.p.o.f	Single point bonded	1969	1,6 km
Waalhaven-Oudeland section 2	800 mm2 Cu	Paper, l.p.o.f	Cross bonded	1969/1976	5,4 km
Waalhaven-Botlek section 1	800 mm2 Cu	Paper, l.p.o.f	Solid bonded	1959	1,6 km
Waalhaven-Botlek section 2	1200 mm2 Al	XLPE	Cross bonded	1990	2,1 km
Waalhaven-Botlek section 3	800 mm2 Cu	Paper, l.p.o.f	Solid bonded	1959	0,9 km
Vondelingenweg-Waalhaven section 1	800 mm2 Cu	Paper, l.p.o.f	Single point bonded	1969	1,6 km
Vondelingenweg-Waalhaven section 2	800 mm2 Cu	Paper, l.p.o.f	Cross bonded	1969	5,4 km
Vondelingenweg-Waalhaven section 3	1200 mm2 Al	XLPE	Single point bonded	1996	3,5 km
Botlek-Oudeland	800 mm2 Cu	Paper, l.p.o.f	Solid bonded	1969	6,6 km
Vondelingenweg-Botlek	1200 mm2 Al	XLPE	Solid bonded	1994	5,0 km

Table 1: Major characteristics of the circuits

Originally the cable Waalhaven-Vondelingenweg was operated as Waalhaven-Oudeland wit. In 1996 it was extended to Vondelingenweg.
Waalhaven-Botlek consists of two cables and an overhead line. In 1990 part of the overhead was replaced by cable during reconstruction of the A-15 motorway and construction of Albrandswaard distribution centre.
Several minor reconstructions were carried out on all circuits, due to failures, reconstructions and grid changes. The major characteristics of the circuits are shown in table 1.

As an example, figure 3 shows a view of the Waalhaven-Oudeland and Waalhaven-Vondelingenweg circuits.
The figure shows the joints and terminations, parts of the oil supply system and the different types of cables used.

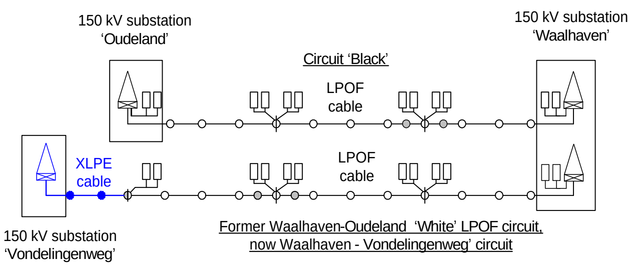

Figure 3: View of 150 kV circuits Waalhaven-Oudeland and Waalhaven-Vondelingenweg

CONDITION ASSESSMENT

As part of the survey, ENECO and Prysmian made a condition assessment.
To assess the condition of the circuits, the following data were checked:

- o impregnation coefficient, to determine gas in oil
- o oil sampling and analysis from joints and terminations
- o visual inspection of earthing systems
- o inspection of hydraulic systems

Figure 4: oil spill at Geervliet

The main results of the condition assessment are:

- o Waalhaven-Oudeland: leakage of oilcontainer at joint 6.
- o Waalhaven-Botlek: oil leakage in the hydraulic system in Geervliet (see figure 4); minor defects in the hydraulic system in Waalhaven
- o Waalhaven-Vondelingenweg: high tan delta in oil, representing some ageing of paper isolation
- o Botlek-Oudeland: high tan delta in oil, representing some ageing of paper isolation

In general the cables are in good condition. Provided that all defects are repaired, continued operation is possible. A new assessment is advised in 5 years.

CALCULATION OF CURRENT RATINGS

During design of the cable circuits a soil thermal resistivity of 0.5 K.m/W was applied. It is known that this value will vary along the cable route. Measurement and verification of soil parameters is necessary to determine the actual current rating.

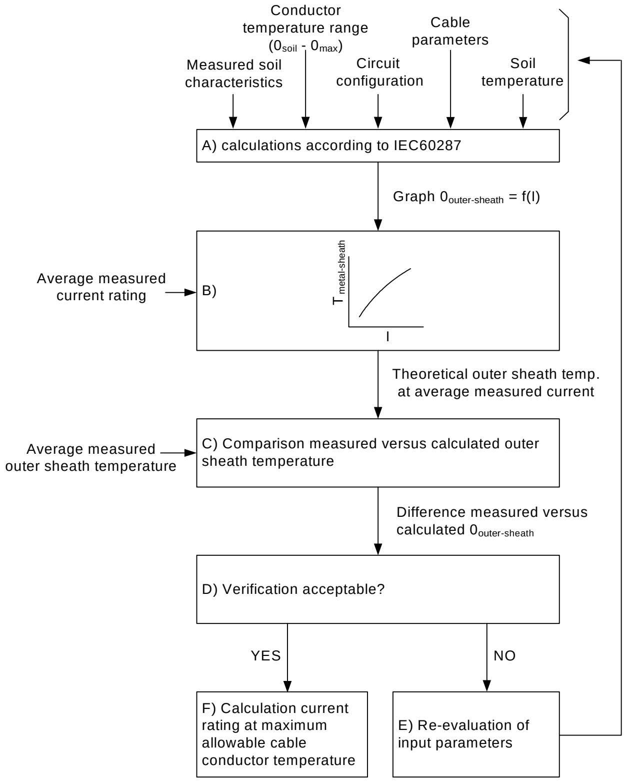

Figure 5: Verification model

Return to Session

Figure 5 shows the model used to determine the circuits current rating.

The circuit configuration, soil characteristics and cable parameters are used as input parameters, to construct a graph [1] of the cable outer sheath temperature as function of the conductor current rating (A).
Please note that the soil temperatures are not measured but are taken from the graph in figure 6

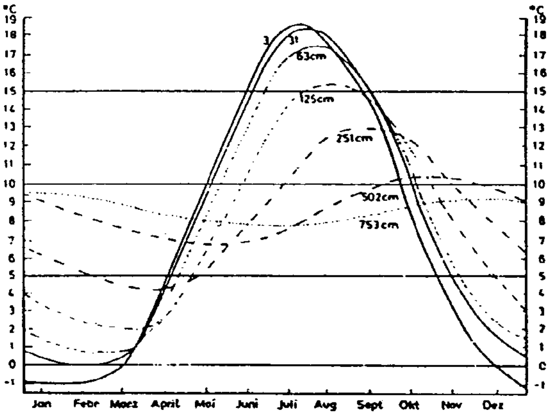

Figure 6: Average soil temperature during seasons for different laying depths

The measured conductor current is averaged over the measuring period. With the aid of the average conductor current and the graph (B) the outer sheath temperature is determined.

The theoretical outer sheath temperature is compared with the average measured outer sheath temperature (C). Differences can occur due to:
- o Limited accurance of measurements
- o Drying out of soil
- o Unknown loads prior to the measuring period of the current.

If the measured and theoretical values do not match within acceptable tolerances (D), the input parameters are re-evaluated (E). If the measured and theoretical outer sheath temperature matches, the maximum nominal current rating is determined by extrapolation (F).

DETERMINATION OF CABLE LAYING CONFIGURATION

A detailed map of the area with the cables is shown in figure 7.

Along the routes of the circuits, a survey was made to determine critical places which could limit the capacity of the cables. These include:
- o places where cables are close to other infrastructures
- o places with possible bad ground conditions
- o places where cables run parallel

At these sites trail holes were made. The cable cross section lay out was determined and compared with the design lay out.

Figure 7: Detailed map of cable trajectories

At most sites only minor deviations were found. In table 2 an overview of the most critical locations is given.

Parameter	unit	Waalhaven-Botlek	Waalhaven – Oudeland	Waalhaven – Vondelingenweg	Oudeland – Botlek	Botlek – Vondelingenweg
Cable construction						
Cable type	[-]	LPOF 1x800	LPOF 1x800	LPOF 1x800	LPOF 1x800	XLPE 1x1200 Al
Max cont. conductor temp.	[°C]	65	65	65	65	90
Max. overload conductor temp	[°C]	65	65	65	65	105 (< 12h)
Laying configuration						
Trail hole reference	[-]	E	3	3	5	1
Laying	[-]	Flat formation	Flat formation	Flat formation	Flat formation	Trefoil
Number of circuits	[-]	1	2	2	1	2
Duct	[mm]	no duct	no duct	no duct	no duct	no duct
Laying depth (covering)	[mm]	1300	1500	1500	1500	1400
C.t.c. phases	[mm]	150 / 5000	150	150	150	Touching
C.t.c. circuits	[mm]	-	700	690	-	1000
Circuit parameters						
Metal sheath earthing	[-]	Solid	XB	XB	Solid	Soild
Λ_1 –losses	[-]	~ 1.3	0.05	0.05	0.68	0.38
Load factor	[-]	0.7	0.8	0.8	0.8	0.9

Table 2: Overview circuit parameters on hot-spot locations

Only the critical situation of Waalhaven-Botlek is due to a changed lay out. The others are caused by unfavourable soil conditions.
At site 'E' in the Botlek-OSP Geervliet circuit, a major deviation exists due to a failure in one of the phases. In the underwater part of the circuit in the Hartelkanaal, the green phase has been replaced by a spare cable from another circuit. This creates a highly asymmetric layout, shown in figure 8. The high sheath loss at this site is visible in table 2, and causes a low current rating of the circuit.

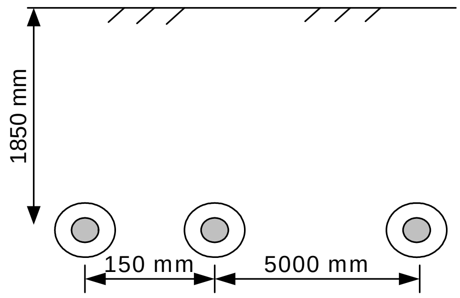

Figure 8: lay out of Botlek-OSP Geervliet at location 'E'

ACTUAL SOIL THERMAL CHARACTERISTICS

Up till the nineties of the last century, an overall soil thermal resistivity of 0.5 K.m/W was used for determining the circuit continuous current rating [3]. Present knowledge reveals that this value is often too optimistic.
The actual soil thermal resistivities are determined by taking soil sample in trail holes. Figure 9 shows the position of the soil samples taken at each trail trench.

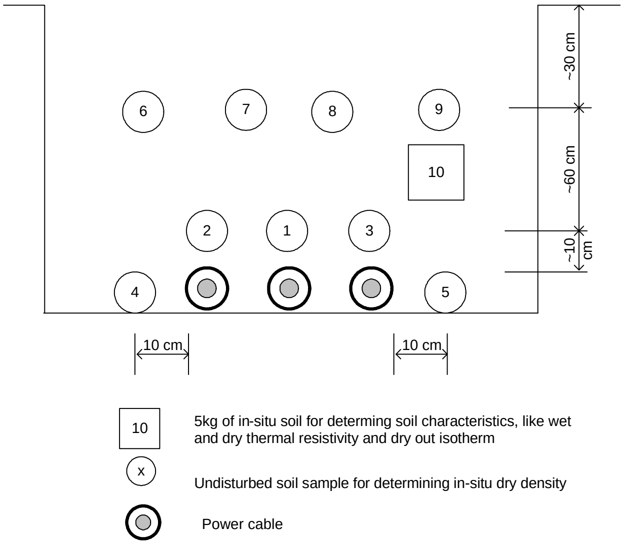

Figure 9: Soil sampling location per trail trench

As indicated in figure 9, the following soil characteristics are determined:

- the in-situ soil thermal resistivity during sampling,
- the nominal in-situ soil thermal resistivity (average value throughout the year)
- the in-situ soil thermal resistivity in dried-out conditions
- the dry-out isotherm of the in-situ soil. Please note this is the isotherm between dry soil and wet soil.

The most critical values and design specifications per circuit are shown in table 3

Circuit:	Waalhaven -Botlek	Waalhaven -Oudeland (zwart)	Waalhaven-Vondelingen weg	Oudeland -Botlek	Botlek-Vondelingen weg
Design value of ground conductivity (Km/W)	0,5	0,5	0,5	0,5	0,5
Design value of critical temperature (C)	45	45	45	45	45
Actual value of ground conductivity at worst site (Km/W)	0,51	0,97	0,86	0,87	0,96
Actual value of critical temperature at worst site (C)	52	24	24	25	28
Critical site	E	3	3	5	1
Designed nominal value of transport capacity (MVA)	200	270	170	182	200

Table 3 'Overview design and measured values at the critical locations for each circuit'

LOAD CURRENT AND OUTER SHEATH TEMPERATURE MEASUREMENTS

At the trail holes, thermocouples where installed on the cable outer sheath. With the aid of a stand-alone data recorder the temperature and the current load through one cable phase were recorded every 5 minutes during several weeks (23-4-2004 to 15-5-2004). A typical sample of the measurements is shown in figure 10.

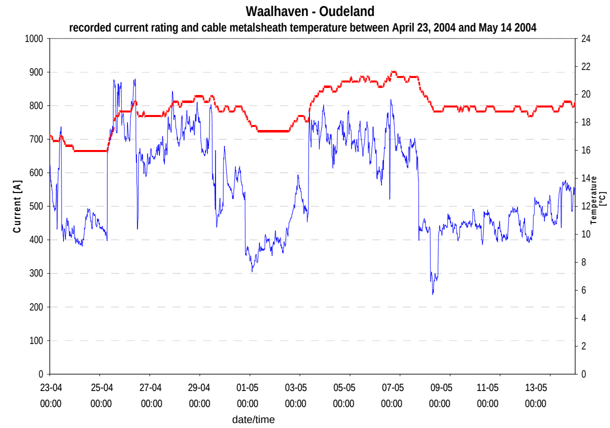

Figure 10: Measured current (thin blue line) and cable outer sheath temperature (thick red line)

As explained in the verification model, the average current rating is determined and the corresponding outer sheath temperature is calculated. Then, this outer sheath temperature is compared with the measured average outer sheath temperature. In those cases where differences are significant, the input parameters are reconsidered. One should consider that circuits under low load result in small sheath temperature rises and the actual undisturbed ground temperature is unknown. Consequently a large uncertainty is expected in the sheath temperature calculation. Or, stated otherwise, a range of soil parameters fits the measured sheath temperature and current curves.
In the survey the determination of the soil parameters of the circuit Waalhaven-Vondelingenweg was quite difficult. This was caused by the low load during the measurements.

Table 4 shows the maximum allowable continuous current rating per circuit based on the worst-case locations. These continuous current ratings are extrapolated from the measured parameters, taken into account the soil characteristics. The design current rating is also given, including the ratio of actual current versus design rated current.

Circuit	Number of parallel circuits in service [-]	Maximum continuous power rating [MVA]	Design rating [MVA]	Percentage actual rating versus design rating [%]
Waalhaven-Botlek	1	121	200	61
Waalhaven – Oudeland	1	135	270	50
	2	107	270	40
Waalhaven – Vondelingenweg	1	135	170	79
	2	107	170	63
Oudeland – Botlek	1	96	182	53
Botlek – Vondelingenweg	1	144	170	85
	2	2 x 126	2 x 170	74

Table 4 :Actual continuous current rating compared to the design continuous current rating

MEASURES TO INCREASE THE POWER RATING

As indicated the actual allowable current rating is considerable lower than the original design ratings. Therefore, for each limiting location, the possibilities are explored to increase the current rating.

- in general, one could consider the load factor and determine the maximum allowable peak current [2]. The load factor is defined as the peak current in a period divided by the average current in the same period. Since the actual current varies in time, the allowable peak load rating will be higher than the average current rating. Figure 15 shows the maximum allowable peak current per circuit, based on the average recorded load factor.

Circuit	parallel circuits in service [-]	Maximum continuous power rating [MVA]	Measured average load factor [-]	Maximum peak power rating [MVA]	Percentage peak rating versus design rating [%]
Waalhaven-Botlek	1	121	0.7	165	83
Waalhaven – Oudeland	1	135	0.8	185	69
	2	107	0.8	150	56
Waalhaven – Vondelingenweg	1	135	0.8	185	109
	2	107	0.8	150	88
Oudeland – Botlek	1	96	0.8	133	73
Botlek – Vondelingenweg	1	144	0.8	158	93
	2	126	0.9	140	82

Table 5: Actual continuous current rating compared to the design continuous current rating

- Application of backfill in those situations where un-favourable thermal characteristics are present. Although this method will be one of the most effective measures in most occasions, it is seldom done because of:
  - the costs
  - the accessibility: hot-spots can not be reached; they are located under highways or they are dredged cables or the cables are installed in directional drillings
  - permits: if cables are installed in or nearby dykes, the original soil must be used to refill trenches.
- Further soil investigation. All measured outer sheath temperatures are obtained at relative low temperatures and this will lead to large tolerances when results are extrapolated. Also the drying out of soil is taken into account in the calculations, but dried out soil has not been detected during the trail hole research. Perhaps the drying out does not occur during cyclic loading and a higher peak load rating is allowed.
- Implement cross bonding and/or single point bonding in those cable systems that are solid bonded.
- Excavate the trench and rearrange laying configuration. In the past, one of the cable phases of ‘Waalhaven-Botlek’ failed and the connection was restored by using a spare phase, resulting in a circuit configuration which is not symmetrical and this leads to relatively high metals sheath losses.
- Replace existing circuits by new cable circuits. Most investigated circuits are 40 years old and, although they are in good shape, the maximum allowable power rating over each circuit lags behind the design value. With this in mind, new circuits can be designed based on the functional requirements and taken into account the environmental conditions.

ACTIONS TAKEN BY ENECO NETBEHEER

As a result of the condition assessment ENECO has carried out the necessary repairs. This was done in the months following the assessment.

To mitigate the asymmetry in Botlek-Waalhaven, new cables were laid under the Hartelkanaal in 2004.
This was followed by the construction of Geervliet 2 substation and a new grid lay out. Today the circuit Botlek-Waalhaven is shortened to Geervliet 2-Waalhaven.

Following the survey ENECO has replaced the design rating by the maximum peak power rating for network operation.
Currently work is in progress to determine whether the new rating influences the network planning or the replacement scheme.

CONCLUSIONS

During time the surroundings of cables can alter considerably, and this may result in lower transport capacity.

A good survey, including determination of soil characteristics and measurement of outer sheath temperature and current can provide information for current ratings. Matching of measured and calculated values needs considerable efforts. In this case the actual ground conditions in comparison with the design specification were detrimental.

The use of the cyclic rating described in IEC 60853 permits a prolonged use of the old 150 kV ENECO cables with moderate reduction in transport capacity.

Glossary:

LPOF	low pressure oil filled
GEB	Gemeentelijk energie bedrijf (municipal energy board)
NKF	NV Nederlandsche Kabelfabriek, now Prysmian cables & systems BV.
OSP	Opstijgpunt (transition compound)
CTC	Core to core
XB	Cross bonded

References

[1] IEC60287, 1994, ‘Calculation of the current rating’

[2] IEC60853, 1989, ‘Calculation of the cyclic and emergency current rating of cables’

[3] KEMA specification S11, 1970, ‘specification for LPOF cables and accessories’, Arnhem, The Netherlands