HIGH-CLASS TRANSIT IN AALBORG

OVERHEAD CATENARY

PRELIMINARY DESCRIPTION OF THE OVERHEAD CATENARY SYSTEM FOR LRT
TECHNICAL NOTE
MAY 2014
HIGH CLASS TRANSIT IN AALBORG

OVERHEAD CATEenary

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1 Resumé

Dette arbejdsnotat indeholder foreløbige overvejelser om køreledningsanlægget til første etape af en letbane i Aalborg.

Det anvendte princip for forsyning af kørestrøm til projektet er et parallelt forsyningssystem. Fra omformerstationerne udgøres forbindelsen til køreledningsanlægget generelt af fire til seks isolerede 240 mm kobberkabler. Disse kabler forbindes til masterne via et bund af føringsrør. For at beskytte køreledningsanlægget mod atmosfærisk overspænding, etableres afledere forbundet til køreledningsanlægget.

Konfigurationen af køreledningsanlægget overholder principperne om dobbeltisolering langs hele linjen og i depotet. Følgende løsningsprincipper anvendes: isoleringsafstand til strømførende dele, beskyttelse gennem frihøjde og beskyttelse via afskærmning.

Placeringen af master til køreledninger skal endvidere tilgodese tilgodese hensyn til zoner med uheldsrisiko, hvilket indebærer, at der i dele af et krydsområde ikke etableres master til køreledninger.

Anlægget kan bestå af én 150 mm² kobberkabel køreledning eller af to 107 mm² køreledninger. Designet af anlægget vil tillade en maksimal afstand på 50 m mellem ophæng på lige strækninger.

Den mindste nominelle højde af køreledningen i laveste punkt i spændet er 4,7 m over skinneanlægget. Den maksimale højde vil normalt være 6,5 m.

Kørestrømsanlægget sektioneres i overensstemmelse med principperne herom.

Systemet for ophæng af køreledninger skal designes og kan eventent integreres med belysningsmaster.

Mellem stationerne i Borgergade og Østerågade er krydset traceet Vesterbro, hvor det vil være nødvendigt at sikre passagemulighed for køretøjer, hvis højde overstiger frihøjden i Limfjordstunnelen. Disse kan principielt være meget høje. Der findes systemer til at løfte køreledningsanlægget, men kun til envis højde.

Ser man bort fra eventuelle særlige løftesystemer ved krydsningen af Vesterbro udgør anlægsoverslaget for kørestrømsanlægget i alt 75 mio. kr.
2 Executive summary

This technical note gives a preliminary description of the overhead catenary system for the first line of tramway in Aalborg.

The principle of traction supply applied for this project is a parallel supply system of tracks. From the substation, the connections with the OCS are generally constituted by four to six insulated 240mm² copper cables. These cables join the catenary masts from the sub-station by multitubular. To protect OCS equipment against atmospheric overvoltage, it is installed surges arresters connected to the OCS.

The OCS configuration systematically respects the principle of double insulation, all along the line, main tracks and in the depot. The following principles are applied: the insulating distance between live part and structure, the protection by clearance, the insulation by barrier.

The installation of OCS mast also respects the principle of the accident prone zone: it is avoided to install mast at some points of an intersection.

The OCS on mainline can be made of a single contact wire with a section of 150 mm² in hard copper or of two contact wires with a section of 107mm². The design of the OCS will reach to a maximum permitted span close to 50 m (in right alignment).

The minimum nominal height of the contact wire above rail level is 4.70m (at lower point in the span). The maximum height of OCS is normally 6.50m.

According to the principle of cantonment, the OCS is divided in sections.

OCS poles have to be carefully designed and could be mutualized with lighting system.

Between Borgergade station and the Østerå station, convoys of exceptional great heights can cross the tramway platform. Lifting systems for catenary exist on the market, but they are limited on height.

Excluding the treatment for special convoys of the section crossing Vesterbro, the estimated cost for the OCS deployment on the Aalborg mainline tramway is 10 097 500 €.
3 Introduction

The OCS is used to deliver energy from Rectifier Substations to the tramway and to insure recovery of the energy during braking phase of the tramways.

The interface with the rolling stock is the contact between pantograph and contact wire. To ensure proper operation of the equipment, this contact must be permanent.

This document is intended to provide for the tramway to the city of Aalborg, depending on assumptions, global solutions and technically coherent for OCS system.
### Definitions

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<td>Control and Maintenance Centre</td>
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<tr>
<td>daN</td>
<td>decaNewton</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
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<tr>
<td>EN</td>
<td>Euro Norm</td>
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<tr>
<td>GLO</td>
<td>Gauge limit obstacle</td>
</tr>
<tr>
<td>HEB or HEM</td>
<td>H beam</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
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<tr>
<td>Km</td>
<td>Kilometer</td>
</tr>
<tr>
<td>kN</td>
<td>kiloNewton</td>
</tr>
<tr>
<td>kV</td>
<td>kiloVolt</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>mm</td>
<td>millimeter</td>
</tr>
<tr>
<td>OCS</td>
<td>Overhead Catenary System</td>
</tr>
<tr>
<td>V</td>
<td>Volt</td>
</tr>
<tr>
<td>VDC</td>
<td>Voltage Direct Current</td>
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<tr>
<td>VLD</td>
<td>Voltage Lower Device</td>
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</table>
5 Code and standards

The OCS equipments are designed in accordance with the latest rules for a tramway line listed in the applicable documents and standards for Power Supply.

Main standards for OCS are listed below:

- EN 50119: Railways application – Fixed installations – Electric traction overhead contact lines;

- EN 50121-1 to 5 Railways application – Electromagnetic compatibility;

- EN 50122 Railway applications / fixed installations -1st part: protection measures relating to electrical safety and earthing;

- EN 50124-1 Railways application – Insulation coordination – Part 1: Basic requirements; Clearances and creepage distances for all electrical and electronic equipment;

- EN 50149 Railways application – Fixed installations; Electric traction – Copper and copper-alloy grooved contact wires;

- EN 50163 Railways application – Supply voltages of traction system;

- EN 50206-1 Railways application – Rolling stock – Pantographs: Characteristics and tests – Part 1: Pantographs for main lines vehicles;

- IEC 60913 Electric Traction Overhead Lines;

- UIC 606-1 Application of kinematic gauges to contact lines;

- UIC 608 Pantographs on international services.
6 General

6.1 Characteristics of the new line of Aalborg
The length of the line is about 12,200 km. This Phase 1 LRT line runs through the city and serves 24 stations. At this moment, the tramway line should be operated with a single rolling stock elements mode.

![Aalborg LRT Phase 1](image)

Figure 1: Aalborg LRT Phase 1

6.2 Vehicle Speed

**Main line**
The maximum operating speed of the vehicles is 70 km/h. All Overhead Catenary System equipments are designed for this authorized speed everywhere on the main track.

**CMC, depot track and switching crossover**
The OCS equipment on CMC, on depot track and switching cross over is designed for an authorized speed of 30 km/h at any point.

6.3 Headway between tramways
The system, in the final of LRT Phase 1 configuration, is designed to achieve an operational headway of 6 minutes.
6.4 Temporary service

In the event of a part of the line is not operable due to an incident, and then a temporary service must be established. To do this, crossovers between main tracks allow the reversal of the rolling stock. The electric traction power is switched off on electrical sections affected by the incident. This recovery mode allows the operation of tramways on temporary service.

![Track map with position of the switches for partial services](image-url)

6.5 Characteristic of rolling stock

Today, final characteristics of the rolling stock are not fixed. However, Systra experts recommend using a tramway of about 32 m and bidirectional.

This type of tramway has only one pantograph and the admissible value of the current during the exchange between OCS and this part of rolling stock vary among 1100 A and 1500 A.
7 Characteristic of power supply

7.1 Principle of the power supply in 750 Vdc
The principle of traction supply applied for this project is a parallel supply system of tracks. Electrical Equipment (OCS included) of the two main tracks are not separated electrically. Consequently, this doesn’t allow single track train operation. The set of both OCS lines (for the two parallel main tracks) is divided into electrical sectors and subdivided into elementary sections (OCS electrically separable minimum section). Between two elementary sections, disconnecting devices are installed.

7.2 Connection between the substation and the OCS
From the substation, the connections with the OCS are generally constituted by four to six insulated 240mm² copper cables. These cables join the catenary masts from the sub-station by multitubular. To the extent possible and in the purpose to reduce the cost, these lengths of connections shall not exceed 200 m.

7.3 Parallel Feeder
A parallel line feeder could be installed along the line to minimize voltage drops. This feeder is connected to both parallel OCS lines every 500m. The connections between OCS lines and feeder are made of two insulated cables, one per each track. These cables are equivalent to 240mm² copper cables.

7.4 Protection against atmospheric overvoltage
To protect OCS equipment against atmospheric overvoltage, it is installed surges arresters connected to the OCS. Surges arresters protect the equipment connected between the OCS and track rail against atmospheric overvoltage.
8 Main assumptions for OCS design

8.1 Conditions Environmental

Climatic Conditions
The oceanic climatic conditions of Aalborg are considered for the design of OCS.

Temperatures
The temperature range to be taken into account for the overhead line is: –25° to +50°Celsius.

Seismic Conditions
No loads or safety factors are taken into account for checking the resistance of structures against earthquakes.

8.2 Safety Factors
Safety factors are consistent with the EN-50119. The coefficients listed below are defined relative to the rupture. The ratio (three) is used and is the minimum for:

- The contact wire (with 20% wear);
- The material suspensions.

The factor-3 (three) is a minimum value for all anchor cables of the categories listed below:

- Slings and lashings;
- All cables for Transversal and gantry flexible (including droppers).

Anchors on facades, chemical fixation and sealing, anchor rods, platinum and eyes must be dimensioned with a minimum safety factor of 3 (three) compared to normally loads applied in the most unfavourable conditions.

All insulating parts are designed with a minimum safety factor of three (3) relative to the rupture.
8.3 Principle of Double Insulation

The insulation of the OCS in relation to the ground will be double in public areas (stations, pedestrian ways). Consequently, the OCS configuration systematically respects the principle of double insulation, all along the line, main tracks and in the depot.

**Insulating distance between live part and structure**

The overhead insulation distance to be respected between a 750 V DC live element and the adjacent structures, without interposition of an obstacle ensuring the insulation, is 100 mm in static condition and 50 mm in dynamic condition (standard EN 50119).

The pantograph is to be considered as a live part. All the neutral parts must be considered as being under 750 V DC voltages.

**Protection by clearance**

For the passage areas, accessible to people, the approach distance in a straight line must be respected as indicated in the figure below in order to avoid any direct contact with the live parts of the overhead contact lines. The pantograph is considered as a live part.

![Figure 3 (taken from standard EN 50122-1)](image)

Clearances to accessible live parts (in meters) on the outside of vehicles as well as to live parts of overhead contact systems from standing surfaces accessible to persons for nominal voltages up to and including 1 kV AC./ 1.5 kV DC Left side of figure refers to areas accessible to the public and the right side is for area non-accessible to the public (maintenance or working staff with special training).
**Insulation by barrier**

If the insulation by distancing cannot be achieved, an efficient device will be used to avoid any direct contact with the live parts. In the case of public areas located above the overhead contact lines, there will be barriers on either side of the structure. These barriers will be consisting of solid screens or wire fences and will respect the standard EN 50122.

![Figure 4: Protective screen](image)

8.4 The accident-prone zones

The presence of fixed obstacles near road and tramway platform intersections can significantly worsen the consequences of a collision between a road vehicle and a tram. It is therefore agreed that the OCS poles along the line and along the access track to the depot are not be implanted in the shaded zones of the diagram below:

![Figure 5: Accident prone zone](image)

The value of the parameter depends on the maximum speed of crossing the crossroads by the trams authorized by RSE (Safety and Operation Regulation) or by the signalling.

<table>
<thead>
<tr>
<th>Tram speed in kph</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
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<tr>
<td>d in meters</td>
<td>6.6</td>
<td>10.2</td>
<td>14.5</td>
<td>19.5</td>
<td>25</td>
<td>31.5</td>
<td>38.5</td>
<td>46.3</td>
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*Table 1: Accident prone zone construction*
9 Technical assumptions for OCS

We can divide the OCS technology for LRT in two main families:

- The first one is OCS composited by one or two contact wires hang by dropper to a messenger wire;
- The second family is OCS only composited by one or two contact wires.

The first family allows high speed of rolling stock; headway reduced and limits the use of parallel feeder cables. However, in case of AALBORG city, the different assumptions about these different considerations no permit to consider the utilisation of this type of OCS, the more so the extra cost for non-useful properties is approximately 20%.

![Figure 6: OCS with messenger wire](image)

The second family allows a sufficient speed on mainline, 70 Km/h, for trams of Aalborg and associated with a compensation system of the temperature variation impact, it limits the installation cost.

![Figure 7: OCS without messenger wire](image)
9.1 OCS composition on mainline
The OCS on mainline can be made of a single contact wire with a section of 150 mm2 in hard copper or of two contact wires with a section of 107 mm2.

9.2 Tensioning of the overhead line
The compensation of temperature effect on an OCS is performed on the main lines OCS. The mechanical tension of the contact wire on the entire temperature range between -25 °C and +50 °C is constant. The copper extension is absorbed by pulley block equipment that insures the function of a mechanical tensioning device. Two tensioning devices can compensate the copper wire extension on a maximum distance of 1500 m (also taking in account anchor devices length).

9.3 Span lengths
Span is the OCS distance between two poles or two suspensions consecutively. The design of the OCS will reach to a maximum permitted span in right alignment close to 50 m, for OCS with tensioning devices. In curve the span distance is limited by the work range of pantograph.

In the case of mixed mast (lighting for example), the addition of lighting console must respect the pegging plan.

9.4 Contact wire Stagger
In alignment as well as in the curves, staggering should be carried out so as to obtain a maximum sweeping of the contact shoe of the pantograph. In alignment, the maximum staggering of the contact wire with the axle of the pantograph is 200 mm. The track deflection in the middle of the span is limited at the time of design studies to 350 mm for radii of curvature greater than or equal to 25 m.

9.5 Contact wire height
The minimum nominal height of the contact wire above rail level is 4.70 m (at lower point in the span). The maximum height of OCS is normally 6.50 m, but this data shall be confirmed by the rolling stock designer.
9.6 Cantonment
During the design phase, the OCS is divided in sections. Two contiguous sections overlapping at their extremities while maintaining the continuity of the contact plan constitute:

- Electrical sectioning, if the sections are electrically separated;
- Mechanical sectioning, if the sections are not electrically separable.

Electrical sectioning location is defined by the electrical sectioning scheme. Normally, a closed sectioning device is used to shunt the overlap during normal operation.

9.7 Poles
Systra advises to use “HEB/HEM" types with symmetric plate in galvanized steel. The poles equipped with a tensioning device are rectangular tubular reconstituted and welded. Inside it is included the entire tensioning device.

**Functionality**

The implanted poles shall perform the following main functions:

- To support the overhead contact lines and protective associated equipment;
- To support the feeder cables to the catenary;
- To support the lightning conductors.

They can also provide additional functions:

- To support public lighting;
- To support road signalling equipment (signs, traffic lights, etc.);
- To support particular local information.

All the functionalities mentioned above are not necessarily cumulative but can be combined.
**Lighting devices on pole**

Lighting system can be installed on OCS poles, however lighting devices and accessories when mounted on poles OCS must be installed at least at a distance of one meter with bare conductors.

The lighting installations (cables, light device, guards) must be designed according to the principle of double insulation between traction voltage and lighting equipment.

![Figure 8: Lighting devices mounted on OCS poles](image)

**Building anchors**

When the constitution of facade and the height of buildings located on each side of the tracks are well known and can authorize this choice, the overhead contact line could be supported by a flexible gantry structures anchored to the facades. However, a particular study will be done for each anchor.

![Figure 9: Building anchors example](image)
**Anchors location**

The distances indicated below must be correlated with distance values of the air clearances. These distances define the prohibited zone for cables anchoring.

*Figure 9: Anchor position on building façade*
Foundations for poles

Dimensioning methodology of superficial foundations shall respect Danish rules. Preferably, the foundations are deep type: bored concrete piles. However, in some case, reinforced concrete foundations can be used. Whatever the type of foundation, the plates of the poles are attached onto the foundations by means of anchor rods.

The foundation masts are dimensioned on the basis of:

- Forces applied on poles by OCS and possibly low voltage equipment (public lighting, etc.);
- Geotechnical properties of soils supporting foundations;
- Buildings in close proximity (bridge pier, building facade, etc.).

![Figure 10: Concrete pile example](image)

9.8 Proximity with buildings

The base distance between the OCS insulated conductors and the building cannot be inferior at 3 meters. Moreover, the pantograph is considered like live part.
10 Structure protection against accidental contact with traction current

Structures and equipment may accidentally come in contact with a live broken overhead contact line. In compliance with Standard EN 50 122, an OCS “zone” shall be defined. This “zone” shall respect the values of Danish Standards. These values are given in the annex G of this Standard.

To ensure the people protection and to be in compliance with the standard, two means of protection can be used:

- Double insulation (traction equipment and overhead contact lines);
- Transformation of the default in a short-circuit default between positive / negative traction circuits via a discharge interval.
11 Installation to be protected

Facilities to be protected are completely or partially conductive structures and metallic structures which may be accidentally energized in case of contact wire breaking or pantograph breakage or derailment, these shall be included in the OCS “zone”. This concerns especially OCS poles accessible to the public.

All others equipment which has to be connected to the protective circuits against traction current: signaling masts, lighting masts, etc...), must be defined and assumed in the concerned specifications. The interfaces shall be fully defined in next phases.

**Figure 11: Protective loop principle**
12 Particularity of the OCS at CMC

The OCS over the depot area connection and in the depot is composed by a single contact wire whose section is 150mm² in hard copper.

12.1 Tensioning of the overhead line

In the depot area (storage and maintenance site of the rolling stock), the contact wire is not regularized. The mechanical tension of the copper wire varies in function of temperature value. The tension value ensures a safety factor of 3 in the most adverse conditions with a wear rate of 20% allowed.

12.2 Electrical sectioning

Generally the rolling stock speed running in depot area is 30 km/h maximum. Also, only SI shall be used for electrical sectioning device.
13 Crossing of special convoys

Between Borgegade station and the Vestera station, convoys of exceptional great heights can cross the tramway platform. The simpler solution to allow the crossing of these convoys, without height limit, is a free OCS zone. This solution implies that the line should be operated with a rolling stock energized by batteries on board or another on board energy storage.

However this solution impacts the cost of rolling stock and the cost of power supply. If an independent rolling stock solution is not accepted, there are some solutions to allow the passage of these convoys exceptional.

13.1 Height inferior to 6,15m

Without important additional cost, height of contact wire contact over the crossroads concerned may be brought to 6,25m instead of 4.70 m.

To reach this result, it is just necessary to gradually increase the height of the contact wire on both sides of the intersection to obtain a height of 6.45m at the level of the last suspensions. The OCS span length will be limited in order to guarantee a minimum height of 6.25m of the contact wire above the crossing.

13.2 Lifting system for OCS under 7,35m

As the first solution, it is necessary to increase the height of the contact wire on both sides of intersection to obtain a height of 6.45m at the level of the last suspensions. The system is intended for lifting OCS. of 6.45m to 7,65 m ( at the level of suspension ), to allow the passage of special convoys. The OCS span length will be limited in order to guarantee a minimum height of 6.25m of the contact wire above the crossing. The assembly consists of a central frame secured to the floor by HEB a plate. A Manual or electric winch provides the movement of the mobile with two double link chain part. Two at four poles are necessary to assume the function.

Figure 12: Powered Pole of lifting system for OCS
13.3 Lifting system for OCS above 7.35m

To allow the passage of Exceptional transport which exceeds the height of 7.35m, it will be necessary to develop a particular system. Indeed, there is no catalogue product to allow this. It likely that a system composed with a retractable or lifting conductor rail system might satisfy the need of the Aalborg city. During the next phase of studies it will be necessary to contact manufacturers of retractable rigid catenary system in order to submit the need of Aalborg city. In particular, the OCS study responsible should contact Furrer and Frey, Rail tech, SP2I SA or Trainance, the main specialist companies.

![Figure 13: Moveable conductor rail system example](image-url)
14 Cost estimates

The Costs contained in this document have been prepared from the SYSTRA feedback for similar projects in the last three years. The costs shown in this document do not take into account the future studies and monitoring costs of works.

The cost estimates provided below:

- Do not include the costs for design and project follow up (it shall be around 25%);
- Do not include any provision for risks (it shall be around 30% at feasibility study stage);
- The costs provided are at the economic conditions of April 2014.

14.1 OCS Price per Kilometer on main line

Below, the different prices of OCS type or location are given for the Aalborg LRT project. The OCS that are evaluated here, are all supported by poles attached to a foundation.

<table>
<thead>
<tr>
<th>OCS constitution</th>
<th>Pole location</th>
<th>Price /per Km of double track in K€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single copper wire</td>
<td>Axial</td>
<td>781</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>855</td>
</tr>
<tr>
<td>Double copper wire</td>
<td>Axial</td>
<td>880</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>960</td>
</tr>
</tbody>
</table>

Lateral location of OCS poles: the poles are located at the limit board of rolling platform or structure gauge of rolling stock.

Figure 13: OCS lateral location
Axial location of OCS poles: the poles are located at the axe of rolling platform.

Figure 13: OCS axial location

14.2 Assumptions for cost estimate

The assumptions used to determine the preliminary cost for the OCS deployment along the main lines, notably, are the followings:

- The line is long of 12.2 double track, and all the length is equipped with OCS;
- OCS is composed of a single and regularized copper contact wire of 150mm² OCS suspensions and poles are mainly located laterally (close to 7.2 Km) and axially (close to 4.5 Km);
- OCS masts are HE type and don't have architectural treatment;
- Foundations for the catenary masts are part of the catenary batch;
- The protective devices (cables loops connected to the poles) for OCS masts against an accidental contact with traction current are deployed throughout the line, except the areas without OCS;
- All works are done during the day;
- If a pooling of the OCS masts with public lighting is possible under certain conditions, the costs of this mutualisation is not taken into account;
- The cables between feeding devices and OCS are not included and are taken in account in the Power Supply specification;
- The voltage indicators of OCS are not included and shall be taken in account in the Power Supply specifications;

The costs associated to the OCS deployment on others technical disciplines are not included, in particular Tracks, Power Supply and Civil Works.
14.3 Preliminary Cost estimate for the OCS deploying
At the economic conditions of 01/04/2014, the estimated cost for the OCS deployment on the Aalborg mainline tramway is 10 097 500 €.

In case only 11.7 km are equipped with OCS (catenary-free zone between Borgergade St and Oster St), the estimated cost for OCS decrease to 9 670 500 €. Nevertheless, the gain on OCS cost would be compensated by the extra-costs due to catenary-free system itself (extra costs on vehicles, extra costs on adjacent substations, etc.).

14.4 Lifting OCS system costs
Below, the different prices for the different systems allowing the crossing of the line by special convoys. Clear that depending on the height required, it needs add the price of system chosen at cost given in the preceding paragraph for the line.

<table>
<thead>
<tr>
<th>Height of convoy allowed by the System</th>
<th>Price for the equipment of one crossing in K€</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.15 m</td>
<td>No additional costs, only some adjustments of OCS are necessaries.</td>
</tr>
<tr>
<td>7.35m</td>
<td>230 K€</td>
</tr>
<tr>
<td>Above 7.35m</td>
<td>300 K€ to 1000 K€, indeed the cost depends functional of the system and the environmental conditions at the foreseen location.</td>
</tr>
</tbody>
</table>