Garrad Hassan

海上风场电力系统

Offshore electrical systems

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内容 Contents

1. 介绍

Introduction

海上风电场电力系统

Offshore wind farm electrical systems

由四个主要要素组成 Consist of four key elements:

海上 Offshore

1. 场内电缆（电力收集系统）Inter-turbine cables (electrical collection system)
2. 海上分电站（如果有）Offshore substation (if present)
3. 输送到海岸的电缆Transmission cables to shore

岸上Onshore

4. 岸上分电站（和岸上电缆）Onshore substation (and onshore cables)

还有Also

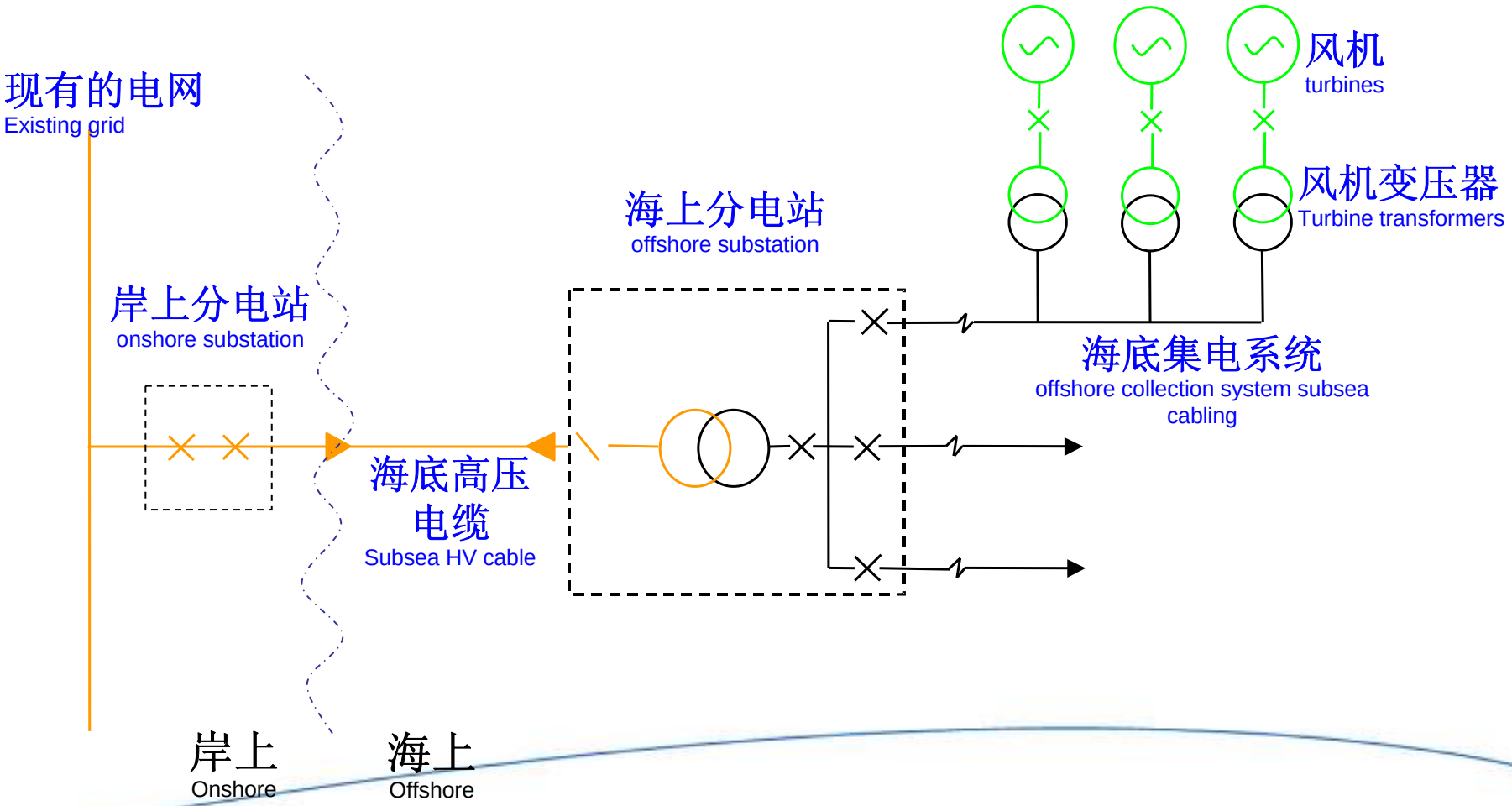
- 风机Turbines
- 电网联接问题Grid Connection issues

常规电力系统介绍

Introduction - general electrical system

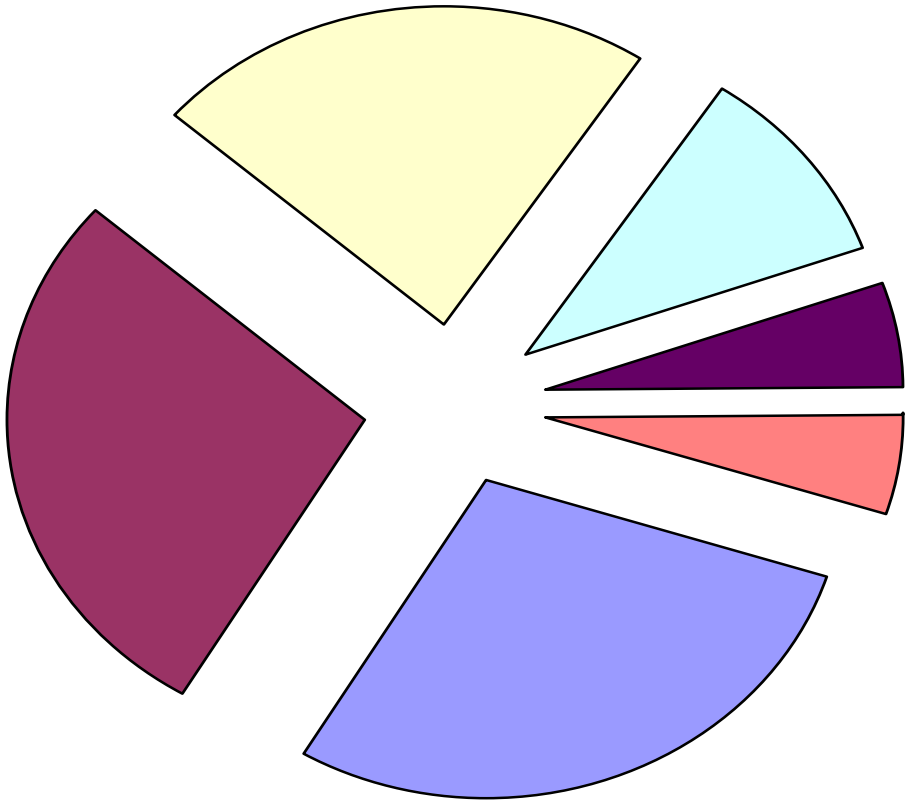
典型的单线框图

Typical Single Line Diagram (SLD)



电力系统成本介绍

Introduction - electrical system costs



占项目成本的20-30%

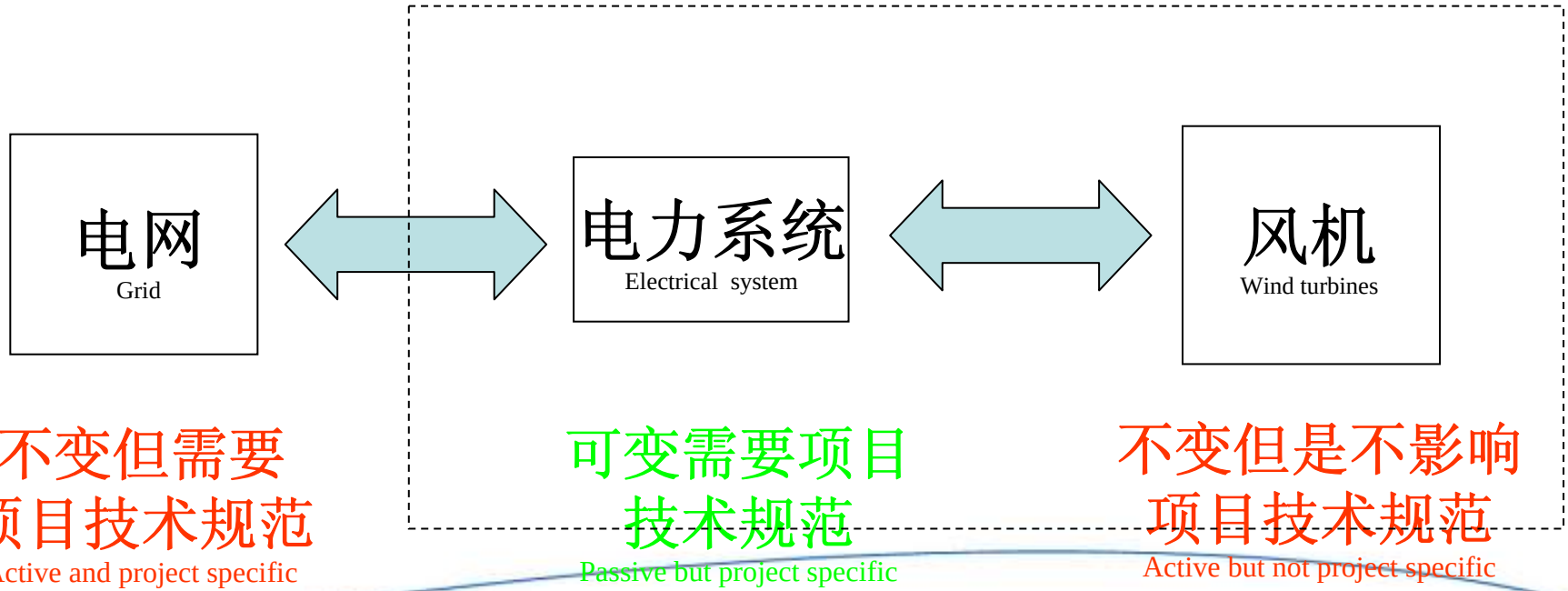
and typically about 20-30% of project costs

技术上相互影响介绍

Introduction - technical interactions

三个电力部分Three electrical parts

- 电网grid
- 风机 wind turbines
- 风电场电力系统wind farm electrical system

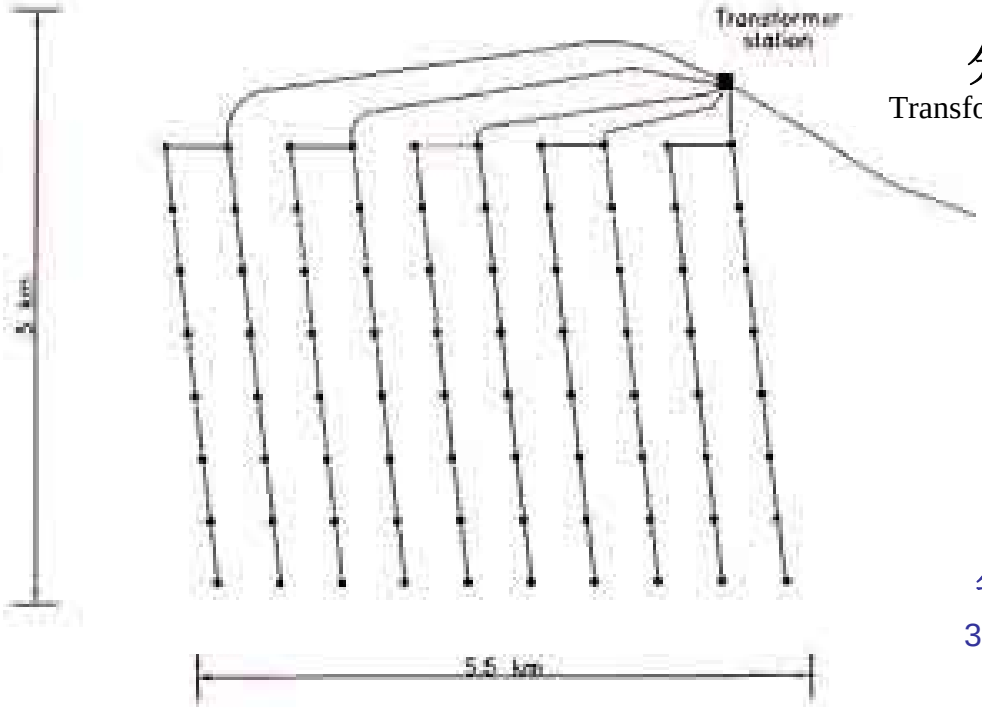


2. 电力收集系统

Electrical collection system

电力收集系统—布局

Electrical collection system - layouts



分电站
Transformer substation

每行32MW
32MW per string

趋向于辐射电路布局，不需额外连接
Trend is for radial circuits without additional links

电力收集系统－电缆安装

Electrical collection systems – cable installation

工具：多数用犁，喷射机，切岩机

Tools – mainly plough, jetter, or rock cutter …

犁

Plough

喷射工具

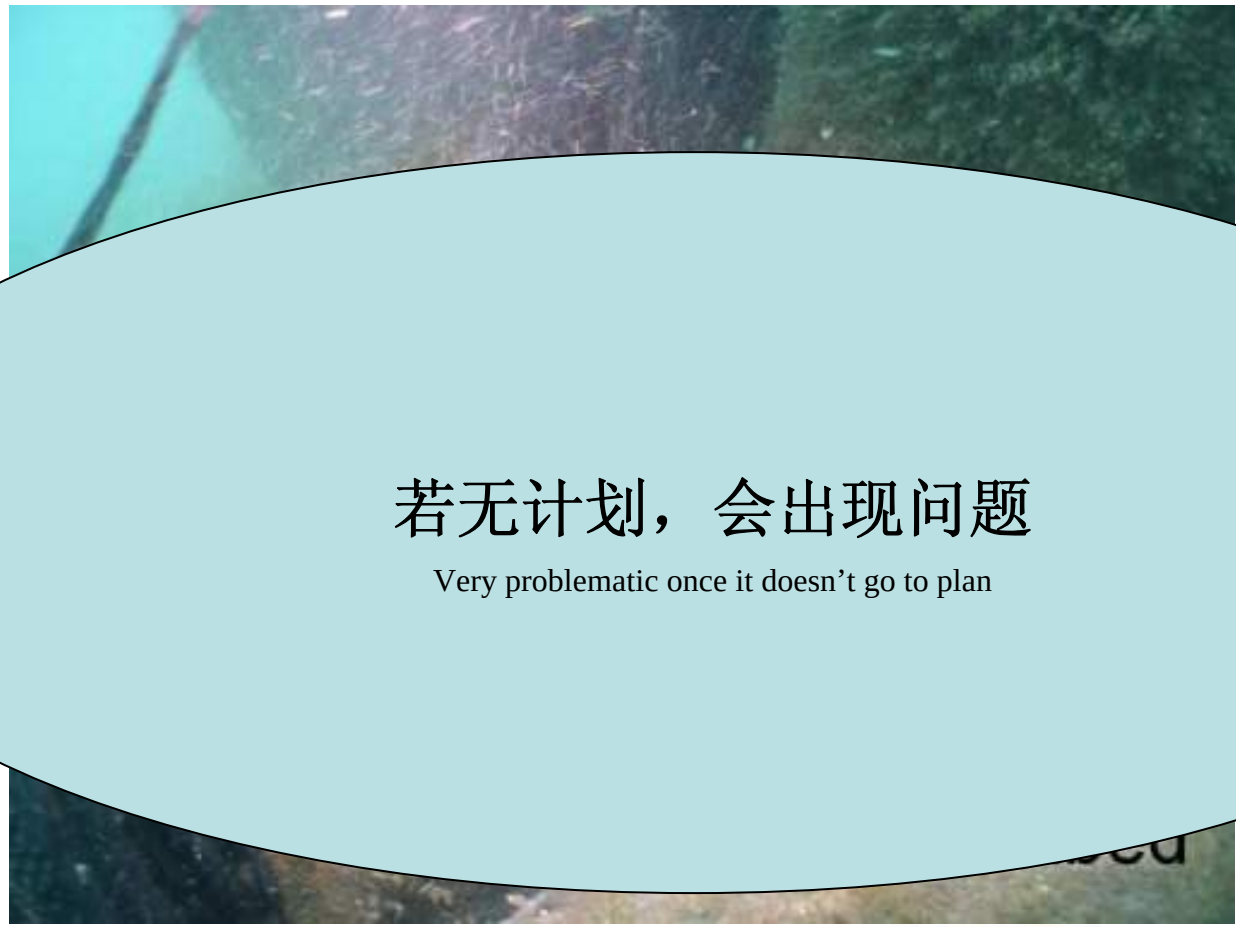
Jetting Tool

电力收集系统－J型管

Electrical collection systems – J-tubes

电力收集系统—电缆J型管入口

Electrical collection systems – cable J-tube entry



若无计划，会出现问题

Very problematic once it doesn’t go to plan

电力收集系统－电缆保护

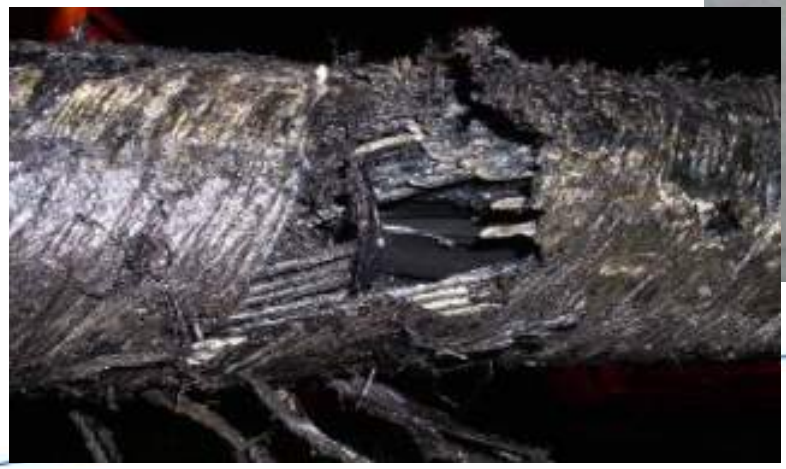
Electrical collection systems – cable protection

70%的电缆故障是人为造成（例如：捕渔装置，锚）

Approximately 70% + of cable failures are due to human activity, e.g. fishing gear, anchors.

埋在地下是最好的保护方法

Burial is the best protection.



电力收集系统—电缆保护

Electrical collection systems – cable protection

埋设成本和可行性决定于土壤条件

Burial cost and feasibility depends on soil conditions

其他方式包括堆石覆盖、沙袋覆盖、和管道

Alternately can rock dump, mattress, pipe.

调查

Survey !

其他危险，例如：沉船、管线

Also other hazards, e.g. wrecks, pipelines

电力收集系统－成本

Electrical collection systems – costs

36kV电缆成本：大约在每公里10万英镑（大约150万RMB）
36kV cable costs in the order of £100k per km

- 一些厂商提供更便宜价格
  some manufacturers may offer better prices.

安装成本：5万-20万英镑再加每公里费用
Installation very variable at £50k - £200k + per km

- 最便宜的方式是使用犁挖法或喷射法在松软的海床上作业
  low end for jetting or ploughing in ‘soft’ seabed.
- 一旦有岩石或冰砾存在，费用显著增加，埋设是不可行的
  once rock or boulders are involved costs can go up dramatically and burial may not be feasible.

电力收集系统－总结

Electrical collection systems – summary

- 辐射布局可用单线可达**30-40**兆瓦
  Radial strings up to about 30-40MW
- 小于36kV电压最佳
  ≤ 36kV voltage optimal
- 电缆类型： XLPE 或 EPR
  Cable types can be XLPE or EPR
- 安装速度大约每天1-2台风机间的连接
  Installation rates of 1-2 inter-turbine lengths per day
- J型管用于风机的出入口
  J-tubes used for turbine entry/exit – fiddly !
- 通常最好采用埋设方法，除非无人类活动和有良好海洋环境
  Generally best buried unless NO human activity and benign sea environment

3. 海上分电站

Offshore substations

海上分电站—介绍

Offshore substations – introduction

有一个海上分电站是必要的吗？
Is it necessary to have an offshore substation ?

如果小项目，例如，**100MW**以下
If the project is small, c. 100MW or less

接近海岸， 例如，**15km**以内
…and close to shore, c. 15km or less

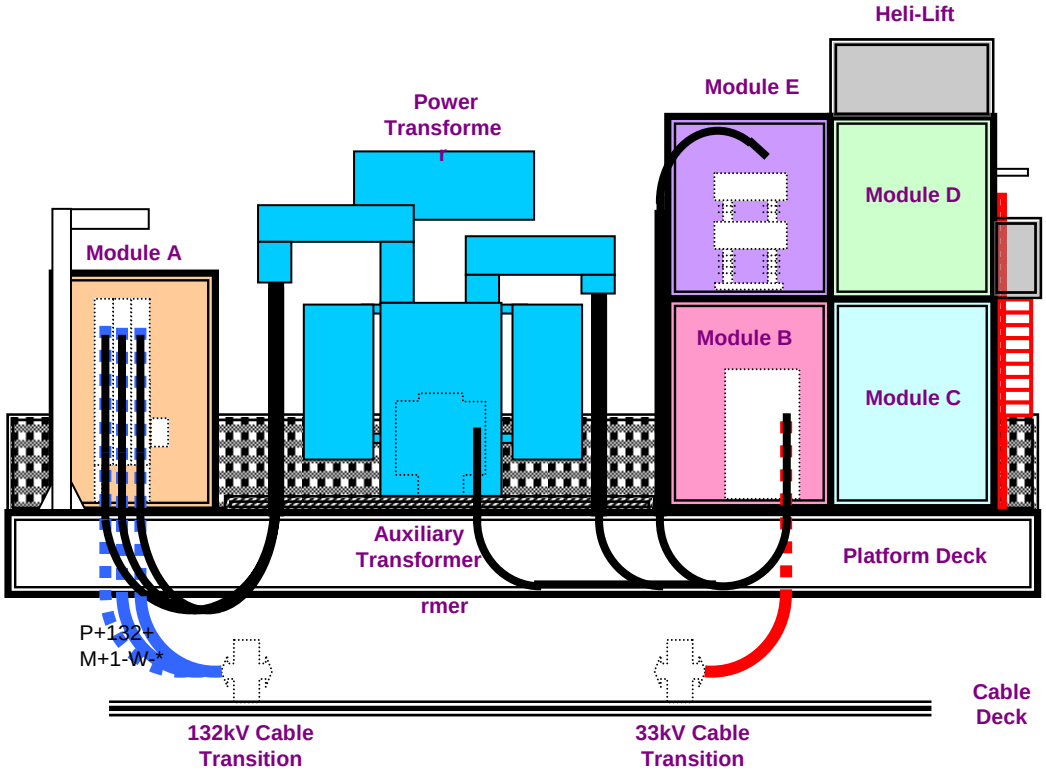
按收集电压连接电网，例如：**33kV**
…and connecting to the grid at collection voltage, e.g. 33kV

答案是：大概不必，否则的话，必须要有
then the answer is probably no, else yes.

多数早期风场项目**(**英国、瑞典,荷兰**)** 符合前两个条件，并且也常常满足第三个条件，因此多数没有一个海上分电站
Most early projects (UK, S, NL) answer yes to the first two questions and often the third. Hence most are without an offshore substation. ,

海上分电站—平板车式结构

Offshore substations – Barrow



海上分电站

Offshore substations

平板车式结构

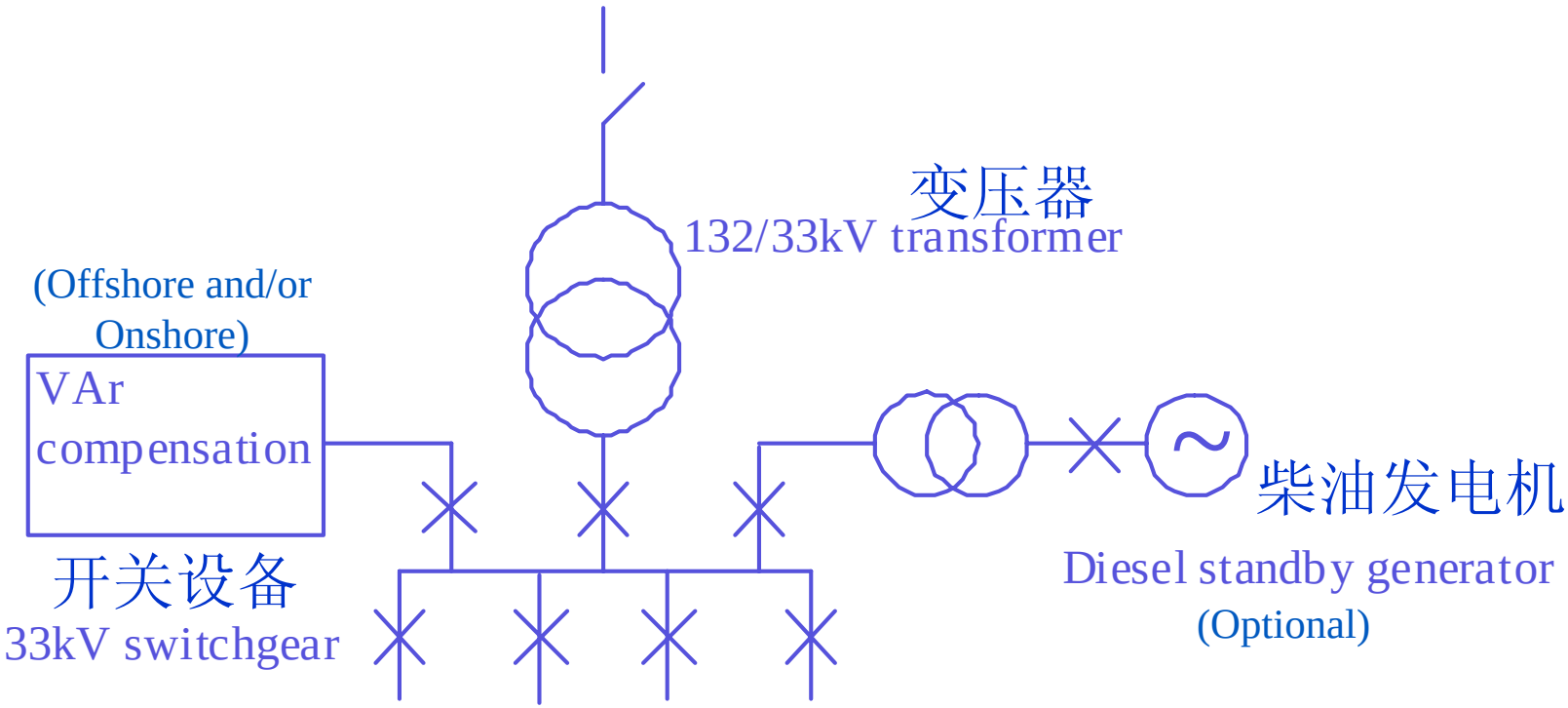
Barrow (Installed)

大型安装工具

Horns Rev

海上分电站—单线框图

Offshore substations – single line diagram



海上分电站－一个或者两个变压器

Offshore substations – one or two transformers?

- 单个变压器，或者两个（＋）并联？ Single transformer, or two (+) in parallel?
- 一个变压器－一旦有故障就是“灾难性的” One transformer - failure is “catastrophic”
- 两个变压器 Two transformers
  - 额外成本 Extra capital cost
  - 针对变压器故障提高安全性 Improved security against transformer failure
    - 更新压器或者修理可能要数月的时间 new transformer or repairs could take months
    - 故障率低（**1**次**100**－**150**年） failure rates are low (1 in 100 - 150yrs)
    - 减少输出取决于变压器的额定值 reduced export depending on transformer rating
  - 较高的运行和维护成本 Higher O&M costs
- 也有其他因素，例如连接到海岸的电缆的数量，额定值等等

  Also other factors such as number of cables to shore, ratings etc …

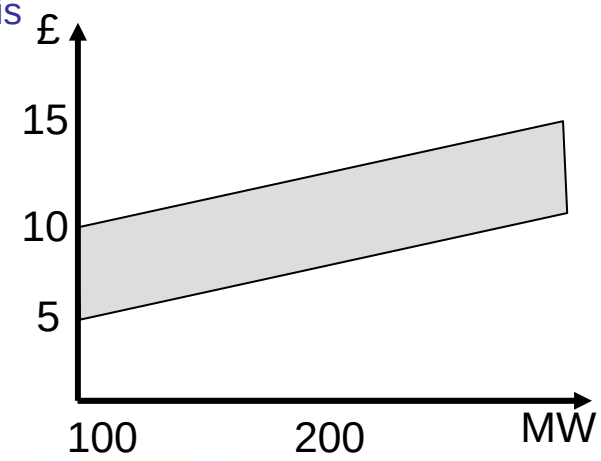
目前的趋势是在可能的情况下使用一个变压器

To date the trend has been for 1 transformer when possible

海上分电站—成本

Offshore substation - costs

- 主要的成本变化取决于支撑结构及其安装
  Main cost variable is the support structure and its installation
- 对于100MW左右的风电场，电气设备要花费2百万英镑
  Electrical items typically £2M for 100MW or so
- 支撑结构和安装可大大超过上述的费用
  Structure and installation can be substantially more than this
- 单桩式更广泛
  Monopile seems to be attractive
- 总的成本5-10百万英镑按兆瓦增加
  Total costs £5-10M increasing with MW



海上分电站－总结

Offshore substations - summary

- 最佳项目： 100MW左右并且远离海岸超过15km，特别是高于36kV的并网情况。
  Optimal for projects approximately above 100MW and 15km+ out to sea, particularly if grid connected above 36kV.
- 安装后的典型成本为5－10百万英镑对于大约100MW的风电场。
  Costs typically £5-10M installed for around 100MW.
- 主要装置是开关设备（36KV，高压）和变压器。
  Main plant is switchgear (36kV and HV) and transformer(s).
- 也可包含备用电源和其他设备，例如：电抗器。
  Back-up supplies and other kit also possible, e.g. reactors.
- 模块式/箱块方法通常先在岸上装好。
  Modular/containerised approach usually taken with substation built onshore.
- 近入方式与风机相同，经常也配备直升机平台
  Access as per turbines, often also with helideck

注意-以上没有考虑 - 直流变频器分电站

NB - DC converter substation not considered above.

4. 输电电缆

Transmission cables

输电电缆-介绍

Transmission cables - introduction

- 传送到海岸电缆
  These are the cables to shore.

- 尺寸问题—距离，电压和兆瓦数是重要的
  Size matters – distance, voltage and MW is important.

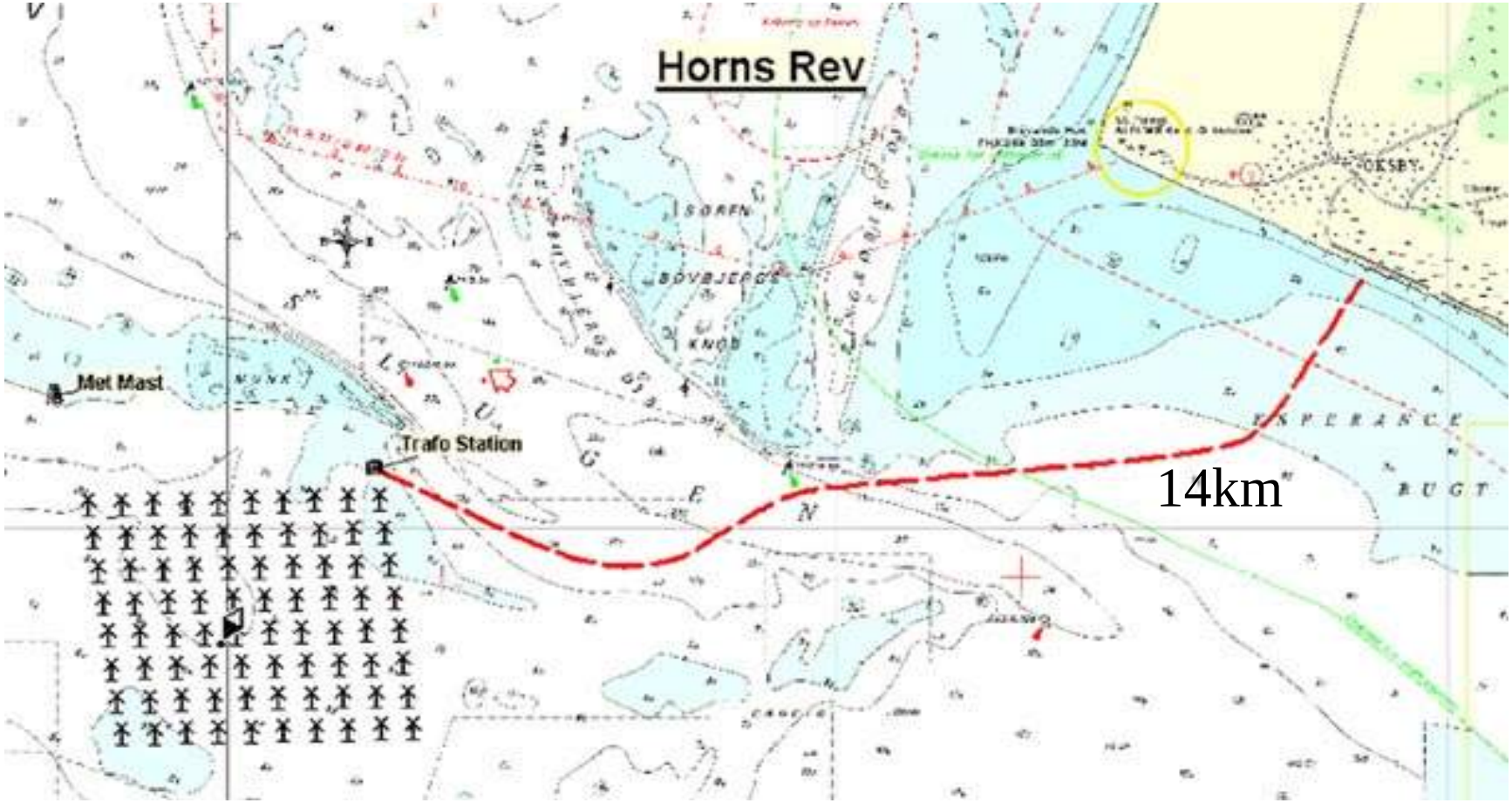
- 一般选择高压并网（即大于**36KV**）Projects grid connecting at higher voltages, i.e. >36kV will probably opt to cable at the grid voltage.
  - 例如 e.g. Horns Rev 风场在150kV @ 150kV
  - Barrow 风场 在132kV@ 132kV

- 至于电缆的结构，安装和保护与风电场内电缆或收集系统电缆类似
  Aspects of cable construction, installation, and protection are similar to the array or collection system cables.

- 电压和无功功率是重要的技术考虑，趋势是使用直流，而不是交流。
  Voltage and reactive power are important technical considerations leading eventually to DC not AC.

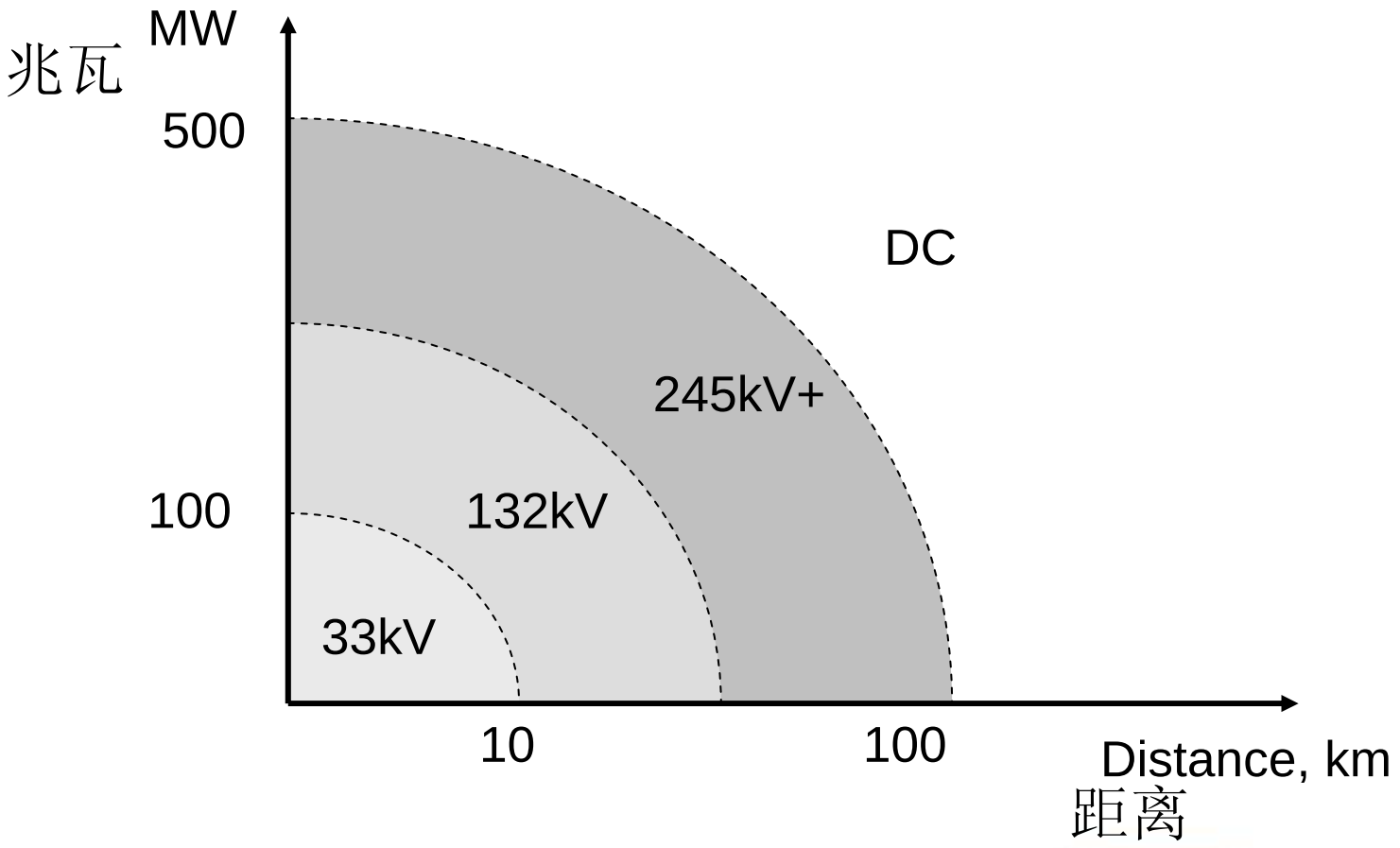
输电电缆— Horns Rev风电场项目

Transmission cables - Horns Rev



输电电缆－电压，兆瓦数和距离的关系

Transmission cables – voltage, MW and distance



输电电缆 交流还是直流 Transmission cables – AC v DC

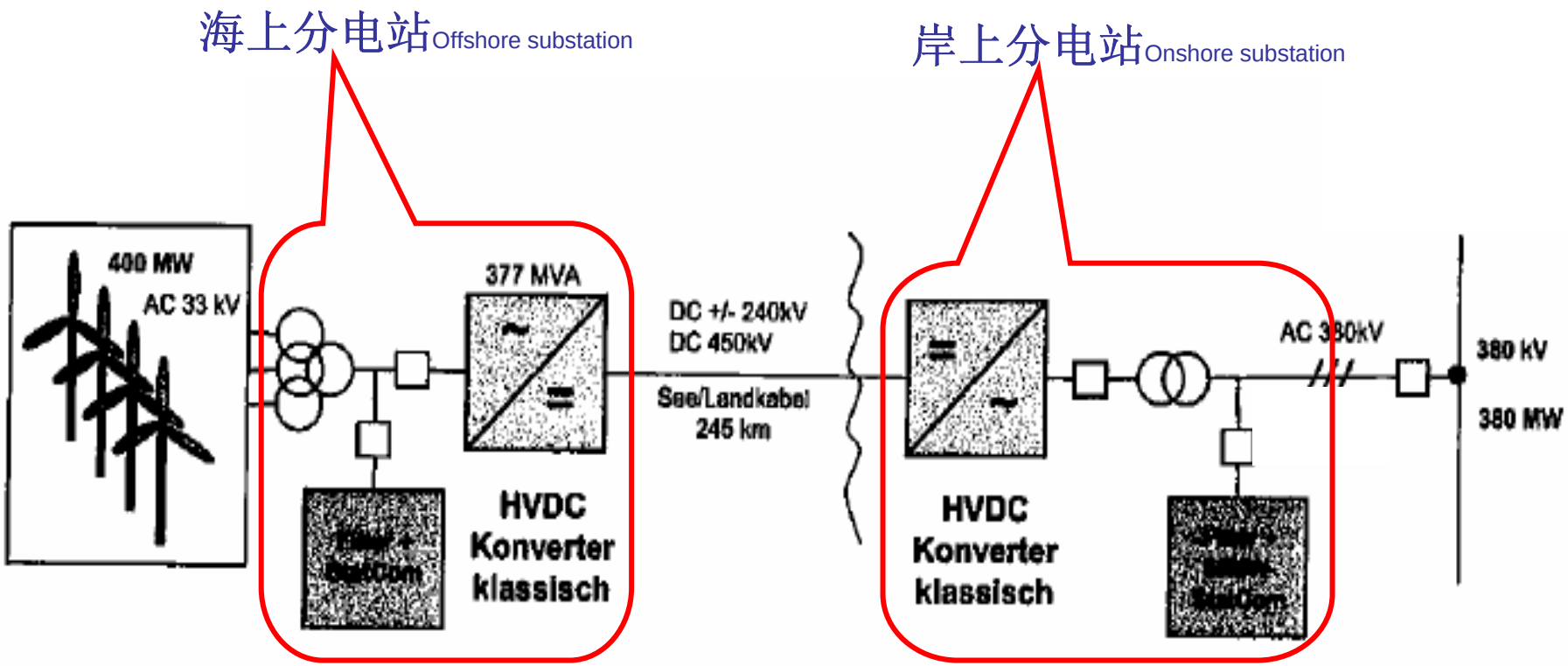
- 交流：AC:
  - 最长电缆长度取决于充击电流（通常为～100Km）
    Maximum cable length is limited by charging current (usually ~ 100 km)
- 高压直流：HVDC:
  - 更廉价电缆，低线路损耗 cheaper cable, lower cable losses
  - 变流器成本，变流器损耗，可靠性
    converter cost, converter losses, reliability
  - 对于长距离输电，取代交流输电方式
    therefore beats AC at longer distances
  - 更廉价的岸上部分 cheaper for onshore section
  - “传统的”高压直流（电流源变流器）：更廉价，更低的损耗
    ‘traditional’ HVDC (current-source converters): cheaper, lower losses, less ‘network-friendly’
  - “高压直流一光”（电压源变流器）：更昂贵，高损耗，更友好的网络
    ‘HVDC-light’ (voltage-source converters): more expensive, higher losses, more ‘network-friendly’

输电电缆—直流选型

Transmission cables – DC options

变流器电站尺寸大，昂贵并且不可避免，必须一个设在海上（另一个在岸上）

Converter stations are big, expensive and unavoidable plus one must be located offshore (and one onshore)



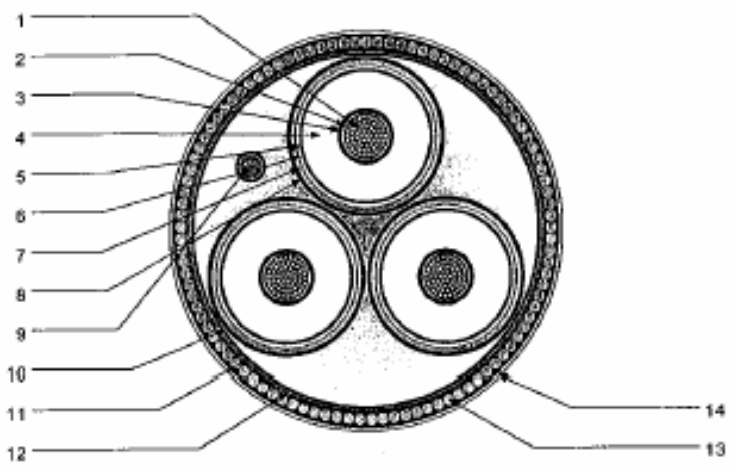
输电电缆—直流电缆

Transmission cables – DC cables

与交流电缆相比，直流电缆是：Compared to AC, DC cables are:

- 简单 Simpler
- 廉价 cheaper
- 比交流损耗低 lower losses compared to AC

AC



DC

输电电缆—成本

Transmission cables – costs

AC

36kV 36kV	对于每行，大约100，000英镑/km as per array at around £100k per km
110-150kV 110-150kV	大约200，000英镑/km （XLPE 类型） around £200k per km (XLPE type)
200-245kV 200-245kV	大约300，000英镑/km around £300k per km
HV DC HV DC	大约100，000英镑/km around £100k per km

（但是兆瓦级的变流器的成本数十兆英镑）

(but converters cost several £10M depending on MW)

输电电缆－总结

Transmission cables – summary

- 高电压是距离、兆瓦数和电网电压的函数
  Voltage is a function of distance, MW, and grid voltage.
- 物理参数类似于场内电缆
  Physical aspects similar to array cables.
- 因此主要输出电缆的保护是非常重要的
  Main MW export cables hence protection is very important.
- 直流费用高，只适用大项目、长距离，例如：数百MW，距离大于100km
  DC is expensive and only worth considering for big projects at long distances – e.g. several hundred MW at 100km +.

5.岸上工作

Onshore works

岸上工作—介绍

Onshore works - introduction

组成：

Consist of:

- 从海底到陆地的电缆转换（岸上登陆）
  Transition from subsea to land cable or line (shore landing).
- 岸上分电站
  Onshore substation
- 并网连接设备
  Grid connection aspects
- 不包括电网风能整合或连接过程的一般问题
  Not going to cover general issues of grid integration of wind or the process of connection.

岸上工作－登陆和转换

Onshore works – landing and transition

最好选择软土容易施工的地方 Hopefully soft and easy.

最好避开海防工程、礁石、或者其他障碍物，要么定向钻孔，要么采取其他措施。

In cases where there are sea defences, rocks or other obstacles, these are best avoided or Directional Drilling or other measures may be necessary.

应用过程中，从深水到浅水到潮汐再到陆地应该制定一个详细的计划。

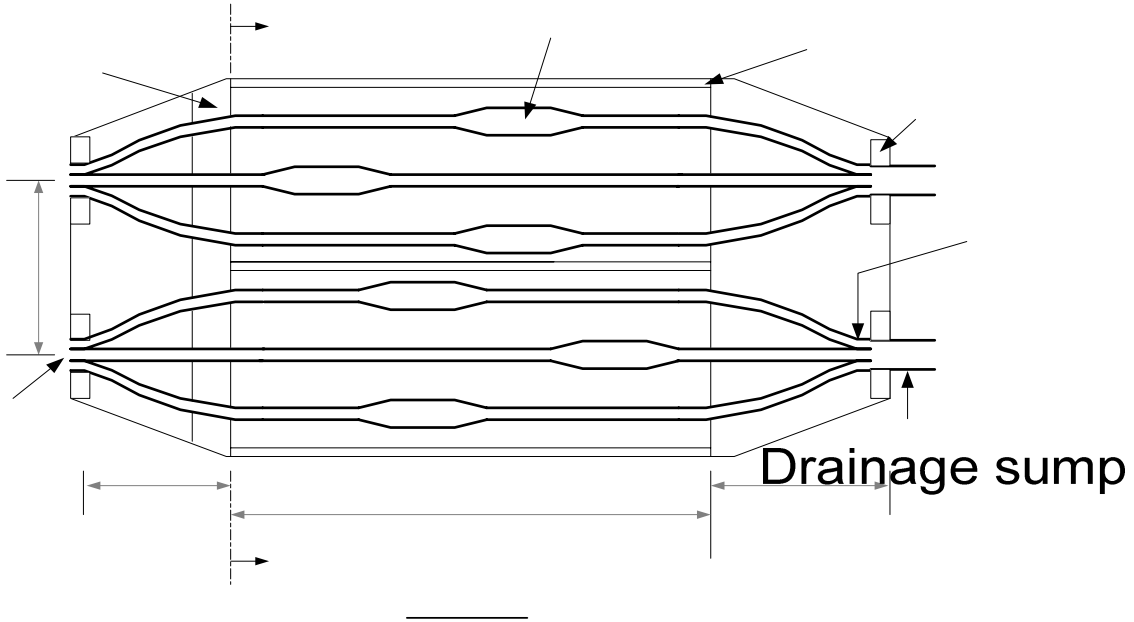
Some planning detail in moving from deep water to shallow to tidal to dry land as applies.

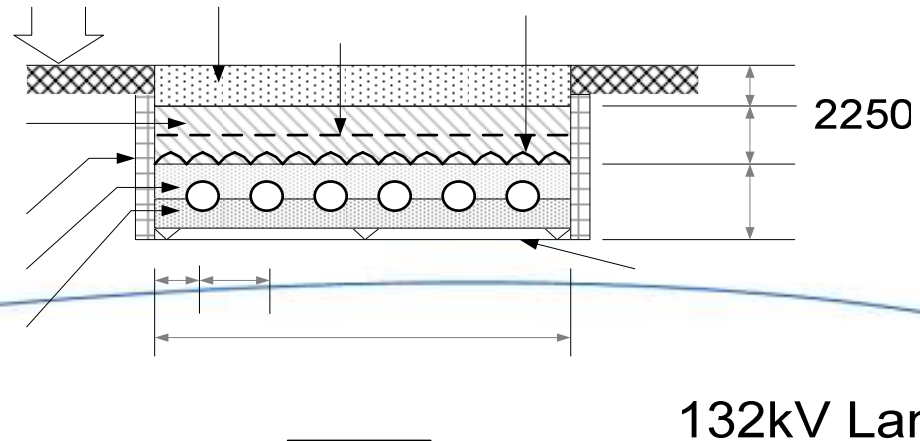
岸上工作－电缆转换

Onshore works – cable transition

右图表示一个简单的高压装置

Drawing shows simple HV vault.





岸上工作—分电站

Onshore works – substation

- 设计可能是由电网公司决定的/但是可能要做一些选择。
  Design may be driven by the Grid Operator / Utility, but there may be some choices to be made.

- 由开关设备、测量装置、变压器连接组成。
  Will consist of switchgear, metering, possibly transformers, and associated plant.

- 海底电缆和遵守电网导则，很可能需要无功补偿。
  Reactive compensation likely to be necessary for the subsea cable and grid code compliance.

- 设计标准
  Standard stuff !

岸上工作－电网要求

Onshore works - grid requirements

需要写入并网协议
These are written into the Connection Offer and Agreements.

应遵守国内和国际标准，具有良好的实用性，但是也要有明确的要求：
General requirement is to comply with national and international standards and good practice, but more specifically:

- MW级
- 正常运行的功率因数 Normal operating power factor
- 界面保护，例如G59 Interface protection, e.g. G59.
- 分布码和电网码－电网的承受力和服务
  Distribution Code and Grid Code – tolerances and services to grid
- 不确定的条款也时有存在，例如：运行限制
  Odd items also occur, e.g. operational constraints
- 功率品质，例如：P.28, P.29, 和 G5/4在英国。
  Power quality, e.g. P.28, P.29, and G5/4 in the UK.
  - 电压阶跃 Voltage steps
  - 闪变 Flicker
  - 谐波畸变 Harmonic distortion
  - 电压紊乱 Voltage unbalance

岸上工作－总结

Onshore works - summary

- 电缆登陆是重要的
  Cable landing is important
- 一般转化为陆地类型电缆或者架空线。
  Normally change to land type cable or overhead lines at shore.
- 改变过程可能是相对简单的
  Changeover can be relatively straightforward.
- 岸上分电站是相对标准化的设计，如果已有海上变压器，那可能仅仅是一个开关分电站
  Onshore substation is relatively standard and with transformers offshore will generally be just a switching substation.
- 无功补偿很重要－长的高压电缆产生数十兆乏的无功功率
  Reactive compensation important – long HV cables produce tens of MVAr.
- 电网运营商的要求是很重要的。
  Grid Operator requirements important.

注意 － 没有涉及电网整合、电网码、补偿及其相关内容

NB - Not talked about grid integration, Grid Codes, grid reinforcement and related.

结束语

Finished

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4. 传输到海岸Transmission to shore
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