Base Load Power Hub (BLPH)

Line Sizing Report

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

1.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

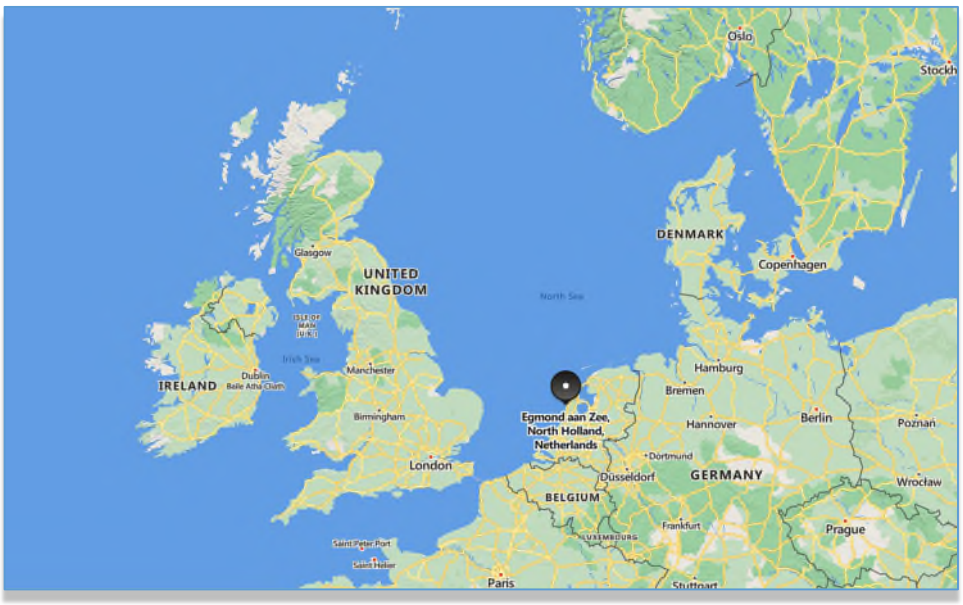


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

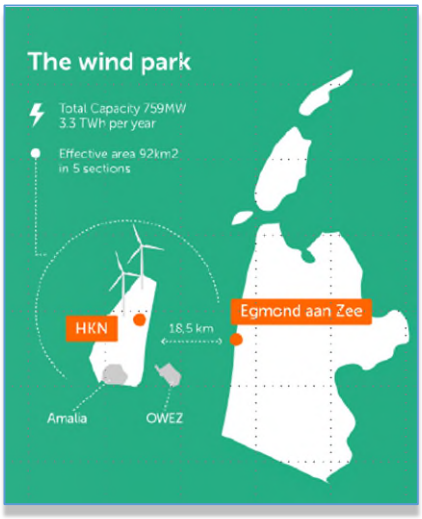


Figure 2 - Wind Park Details

The wind farm will consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

1.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topsides and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

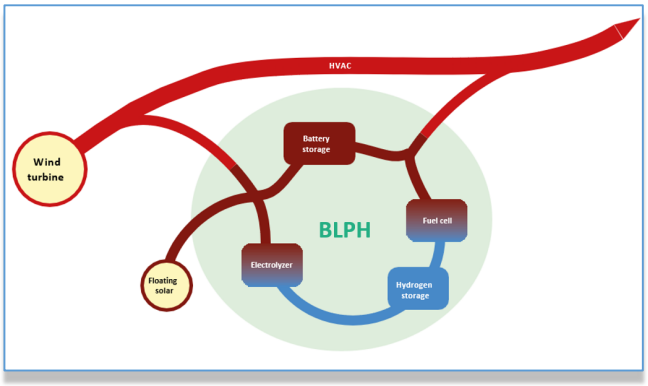


Figure 3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH is to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

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2 DOCUMENT SCOPE

The scope of this line sizing report is to determine the appropriate diameter of the main lines of the piping system relavant to the BLPH offshore plant. In turn, the report is used to fill in appropriate data on P&IDs, datasheets, and line lists. The main purpose of line sizing is to meet design process parameters and criteria such as those related to flow, velocity, momentum, pressure losses. The line size is determined with proper sizing calculations considering various parameters in accordance with COMPANY's design engineering practices.

2.1 REFERENCES

Project Documents

Ref. [1] Basic Design Engineering Package_Rev2 - Document No: K559-2254-PM-PLN-003

Ref. [2] Heat And Mass Balance - Document No: 123A90-DDL-PR-BL-80002

Ref. [3] Relief, Vent and Blowdown Report - Document No: 123A90-DDL-PR-RE-80030

Ref. [4] Chemicals-Utility Consumption Report - Document No: 123A90-DDL-PR-RE-80037

Ref. [5] BLPH PROCESS FLOW SCHEME ELECTROLYSER AND HYDROGEN DRYING PACKAGE – Document No: 123A90-DDL-PR-DG-80003

Ref. [6] BLPH PROCESS FLOW SCHEME HYDROGEN STORAGE – Document No: 123A90-DDL-PR-DG-80004

Ref. [7] BLPH PROCESS FLOW SCHEME FUEL CELL PACKAGE – Document No: 123A90-DDL-PR-DG-80005

Ref. [8] BLPH UTILITY FLOW DIAGRAM WATER TREATMENT PLANT – Document No: 123A90-DDL-PR-UFD-80006

Ref. [9] BLPH UTILITY FLOW DIAGRAM INSTRUMENT AIR AND NITROGEN SYSTEMS – Document No: 123A90-DDL-PR-UFD-80007

Ref. [10] BLPH UTILITY FLOW DIAGRAM VENT SYSTEMS – Document No: 123A90-DDL-PR-UFD-80008

International Codes and Standards

For a list of external, Industry and/or Vendor Standards as well as for a list of Shell DEPs that shall be applied to the project, reference shall be made to Section 10 of Ref. [1].

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2.2 DEFINITIONS AND ABBREVIATIONS

DEFINITIONS

COMPANY or Client (CPY):	Crosswind
CONTRACTOR (CTR):	ROSETTI MARINO S.p.A.
PROJECT:	HOLLANDSE KUST NOORD WIND PARK Project

Table 1 - Definitions

ABBREVIATIONS

BDV	blowdown valve
BESS	battery energy storage system
BFD	block flow diagram
BLPH	base load power hub
CCR	central control room
c.a.	corrosion allowance
CPI	company provided item
CS	carbon steel
ΔP	pressure drop
D/S	downstream
EPCI	engineering procurement construction installation
FC	fuel cell
FCV	flow control valve
FEED	front-end engineering design
FIT	flow induced turbulence
FIV	flow induced vibration
FVF	fluid viscosity factor
Fv	flow induced vibration factor
HKN	hollandse kust noord
H&MB	heat and material balance
KOD	knock out drum
IA	instrument air
ID	internal diameter
ISBN	international standard book number
JT	Joule-Thomson
LOF	likelihood of failure
LP	low pressure
MEG	mono ethylene glycol
MSm³/d	millions of standard cubic meters per day (@ 1 atm and 15°c)
N.A.	not applicable
NPSHr	net positive suction head (required)
NPSHa	net positive suction head (available)
OD	outside diameter
PCV	pressure control valve
P&ID	piping & instrumentation diagram
PFD	process flow diagram
PFS	process flow scheme

PSV	pressure safety relief valve
PV	photovoltaic
RO	restriction orifice
SS	stainless steel
SW	seawater
THK	thickness
TQ	technical query
UFD	utility flow diagram
U/S	upstream
WTG	wind turbine generator
Ve	erosional velocity

Table 2 - Abbreviations

3 LINE SIZING

3.1 GENERAL

As a general principle, the line sizing activity must satisfy pressure drop, flow velocity requirements, and if applicable, especially where two-phase flow conditions can occur, the erosion-corrosion criteria.

The line sizing criteria have also been developed with the aim of providing the best possible sizing, thus in principle preventing unnecessary costs, overweight, and space congestion of piping systems.

3.2 PERMESSIBLE PIPE SIZES

Nominal pipe size of 5 inches and 22 inches are avoided in calculations because they are considered uncommon sizes and out of the ordinary.

The pipe sizes in table below shall be taken into consideration:

DN 15 (NPS 1/2)	DN 200 (NPS 8)
DN 20 (NPS 3/4)	DN 250 (NPS 10)
DN 25 (NPS 1)	DN 300 (NPS 12)
DN 40 (NPS 1-½)	DN 350 (NPS 14)
DN 50 (NPS 2)	DN 400 (NPS 16)
DN 80 (NPS 3)	DN 450 (NPS 18)
DN 100 (NPS 4)	DN 500 (NPS 20)
DN 150 (NPS 6)	DN 600 (NPS 24)

Table 3 - Abbreviations

In addition:

- due to their vulnerability to damage and their limited mechanical strength, sizes DN 15 (NPS ½) and DN 20 (NPS ¾) should not be considered except for short branch connections
- nominal pipe size in pipe racks shall not be less than DN 40 (NPS 1-½)

As well as the exact thickness allowed by piping class is used for the calculation of the fluid velocity (without considering any pipe mill tolerance).

3.3 DESIGN MARGIN

The Heat and Material Balance Sheets (Ref. [2]) have been considered to perform the line sizing activity. No other design/safety margin has been applied in calculation.

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3.4 EXCLUSIONS

The methods and criteria described in the present report **do not cover** the following topics:

- Relief piping (that is covered by Relief, Vent and Blowdown report (Ref. [3])
- Fire water lines

3.5 INTERNAL PIPE ROUGHNESS

For the purpose of the present report, the following internal roughness values are considered:

PIPING MATERIAL	ABSOLUTE ROUGHNESS ε
CS non-corroded	50*10E-6 m
CS corroded	500*10E-6 m
CS flare lines	500*10E-6 m
SS	50*10E-6 m
Titanium and Cu-Ni	50*10E-6 m
GRP without liner	20*10E-6 m
GRP with liner	5*10E-6 m
PVC	5*10E-6 m
Galvanized CS	150*10E-6 m
Drawn tubing	1.5*10E-6 m

Table 4 – Internal pipe roughness

3.6 SIZING CRITERIA FOR SINGLE PHASE LIQUID LINES

Where pressure drop is not a determining parameter, the size should be determined by the velocity constraints.

The velocities shall be kept low enough to prevent problems with erosion, water hammer, pressure surges, noise, and vibration and reaction forces. In some cases, a minimum velocity is required.

For water, preliminary line pipe sizing should be based on Table below:

TYPE OF WATER	MIN VELOCITY (m/s)	MAX VELOCITY (m/s)			
		CS	*SS*	*Cu-Ni*	*GRP*
Fresh water/ Potable water	1.5	4	5	3	6
Sea water/ brackish		3	5	3	6

Table 5 – Typical Water velocity in pipe

For liquids other than water, velocities in accordance with ISO 13703/API RP 14E are used for preliminary line pipe sizing then in the range of 0.5 m/s to 5 m/s.

In regard of **pump suction lines**, special constraints shall be considered on pressure drop in design:

- 0.034 bar/100 m to 0.083 bar/100 m for liquids within 15 °C of their boiling point
- 0.150 bar/100 m to 0.400 bar/100 m for subcooled liquids

Instead for **pump discharge lines** sizing should be based on pressure drop of 0.15 bar/100 m to 0.627 bar/100 m.

For piping systems where the process fluids are expected to be contaminated by sand, the following maximum velocities should be used for preliminary line sizing (in accordance with NORSOK Std. P-002):

- up to 5 m/s for carbon steel
- up to 7 m/s for stainless steel/duplex stainless steel

In cases of intermittent flow, a higher design velocity might be considered as the cumulative effect of the higher velocities might not be an issue.

Moreover, pressure drops for a piping system are calculated by means of the general equation for pressure drop:

$$\Delta P = \lambda \frac{L}{Di} * \frac{1}{2} \varrho v^2$$

Where:

λ: is the friction factor

L: is the pipe length

Di: is the internal diameter of pipe

ρ: is the fluid density

v: is the fluid velocity

3.7 SIZING CRITERIA FOR SINGLE PHASE GAS LINES

3.7.1 General

When sizing gas lines, the sizing criteria is a tradeoff between the maximum velocity and allowable pressure drop. Single-phase gas lines should be sized so that the resulting end pressure is high enough to satisfy the requirements of the next piece of equipment or path. Where pressure drop is not a critical aspect, the requirements in Sections 3.7.3 below should be used. Instead, where the pressure drop is critical, the recommendation in Section 3.7.4 should be used.

Piping with gas at the dewpoint and/or with some droplets shall be designed as gas lines.

For the application of the following line-sizing criteria, the boundary between gas and liquid/multiphase services is set at a liquid fraction of 5% volume in actual conditions.

Gas piping systems containing significant levels of liquids should be sized according to the rules for multi-phase flow (this is not the case).

This section covers normal process lines and as said excludes flare lines where higher velocities and Mach numbers are allowed and shall be checked.

The sizing of gas lines depends on either:

- Velocity, when the pressure drop is not critical, or
- Pressure drop when it is.

Pressure drop is deemed critical when (for instance):

- The cost savings in reduced line size are outweighed by incremental capital and operating costs of downstream or upstream equipment such as compressors
- JT expansion can result in liquid drop out in critical lines such as those between the suction scrubber and compressor

It should also be recognized that high-pressure drop is associated with increased noise, vibration and erosion.

3.7.2 Minimum velocities

There are generally no minimum velocity criteria for lines handling single-phase gas above its dew point.

3.7.3 Maximum velocities

The velocities shown in the table below may be used for preliminary line sizing purposes:

Air and other gases (non-corrosive/non erosive)	10 to 20 m/s
	Max 60m/s where $\rho v^2 \leq 50000$ Pa is maintained
Saturated steam	15 to 30 m/s
Superheated steam	30 to 60 m/s
Vacuum pipes	10 to 100 m/s

Table 6 – Typical gas velocities in pipe

For the sizing of gas lines equations from ISO 13703/API RP 14E are taken into account.

3.7.4 Typical pressure drop values

Where pressure drop is critical the following table may be used as general guideline:

OPERATING PRESSURE (barg)	Pressure drop (bar/100m)
0 to 35	0.001 to 0.11
35 to 138	0.11 to 0.27
Over 138	P*/500

Table 7 – Typical gas velocities in pipe

P* is the operating pressure in bar.

Pressure drops are calculated with the same general equation as shown at the end of the above section 3.6. (within the limit of 10% pressure drop of the upstream pressure).

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3.8 SIZING CRITERIA FOR GAS/LIQUID TWO PHASE LINES

For the purposes of the present study the two-phase flow regime is not envisaged, thus it is not treated as case.

4 RESULTS AND CONCLUSIONS

In regard of process data the line sizing calculation and the related input data refers mainly to H&MB cases (Ref. [2]):

- CASE 1: Electrolyser is "on", and hydrogen is being stored, BESS is charging if required. FC is "off".
- CASE 2: FC is "on", and hydrogen is being used, BESS is discharging if required. Electrolyser is "off".

The performed calculation does not arise any significant concern and does not show non-compliance with the COMPANY's design engineering practices such as DEP 31.38.01.11-Gen. Feb.2018.

The calculation details are attached to the present report as APPENDIX 01.

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5 APPENDICES

5.1 APPENDIX 01 – LINE SIZING CALCULATION SHEET

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		PROCESS LINE SUMMARY SHEET		Appendix 01 Sh. / BY:	1
PROJECT:	**BASE LOAD POWER HUB (BLPH)**				rev.01
PLANT/UNIT:					
Line extremities	From A-50000 To A-20000	From A-20000 to V-25001A/..F	From A-20000 to B-50014		
Line n°	1"-DM-001-01SS-E	1"-HY-007-03HSS-N	1"-DM-005-01CS-H		
Stream n°	<1>	<2>	<4>		
Reference file/case	H&MB CASE 1	H&MB CASE 1	H&MB CASE 1		
I N P U T					
Stream description	Electrolyser feed water	Electrolyser Hydrogen production	Electrolyser Water Effluent		
GAS FLOW					
Flow rate, Kg/h		45.00			
Molecular Weight		2.02			
Pressure, Bar g		30.00			
Temperature, C		65.00			
Compr. Factor (Z)		1.00			
Viscosity, cP		0.01			
Cp/Cv @ Oper. Cond.		1.42			
LIQUID FLOW					
Flow rate, Kg/h	811.40		405.00		
Density, Kg/m3	1,007.70		1,007.50		
Viscosity, cP	0.90		0.90		
LINE (note)	ND 1"	ND 1"	ND 1"		
Inner Diameter, inches	**1.05**	**1.05**	**0.96**		
Length, m (note)	100.00	100.00	100.00		
Roughness (std.=.00015 ft),ft	0.00	0.00	0.00		
FITTING (note)					
Res. Coeff. (K)					

Note : in case of FITTING, the length must be 0 but the inner diameter and the roughness must be specified. CAUTION! K values must be corrected by the ratio: f(at calc'd Reyn.)/ f(constant at complete turbolence)

O U T P U T				
Dens* Vel^2, $kg/s^3/m^2$ (<15000)	**162.27**	**226.16**	**58.41**	**0.00**
Gas density, kg/m^3	0.00	2.22	0.00	0.00
Fluid density, kg/m^3	1,007.70	2.22	1,007.50	0.00
Fluid viscosity, cP	0.90	0.01	0.90	0.00
Total Flow rate, kg/h	811.40	45.00	405.00	0.00
Reynold's Number	11,997.97	60,926.15	6,579.99	0.00
Darcy friction Factor (Fd)	0.0322	0.0253	0.0369	0.0000
Equivalent Res. Coeff.	120.75	95.12	151.84	0.00
Total Press. Drops, Psi	1.42	1.56	0.64	0.00
Press. Drops, Psi/100 ft	0.43	0.48	0.20	-
Fluid velocity, ft/s	1.32	33.09	0.79	0.00
Total Press.Drops, Bar	**0.0980**	**0.1076**	**0.0444**	**0.0000**
$100/Dens^{0.5}$, ft/s	-	268.38	-	-
Fluid velocity, m/s	**0.40**	**10.08**	**0.24**	**0.00**
Sonic Velocity, ft/s	0.00	4,614.07	0.00	#DIV/0!
Dens* Vel^3, kg/s^3	65.12	2,280.68	14.06	0.00
Flow type :	Turbulent	Turbulent	Turbulent	no flow

	PROCESS LINE SUMMARY SHEET		Appendix 01 Sh. / BY:	2 /
PROJECT:	**BASE LOAD POWER HUB (BLPH)**			rev.01
PLANT/UNIT:				
Line extremities	From V-25001A/..F To 25PV055	From 25PV055 to A-80000	From A-80000 to B-50014	From P-50001A/B to A-50000
Line n°	1.5"-HY-148-03HSS-N	2"-HY-023-01HSS-N	1"-DI-012-01CS-H	1.5"-SWS-031-01SD-E
Stream n°	<5>	<6>	<7>	<20>
Reference file/case	H&MB CASE 2	H&MB CASE 2	H&MB CASE 2	H&MB CASE 1
I N P U T				
Stream description	H2 to pressure reduc.for Fuel Cells	Fuel Cells H2 Feed	Fuel Cells Water Effluent	Seawater intake
GAS FLOW				
Flow rate, Kg/h	106.00	106.00		
Molecular Weight	2.02	2.02		
Pressure, Bar g	30.00	6.50		
Temperature, C	25.00	25.00		
Compr. Factor (Z)	1.00	1.00		
Viscosity, cP	0.01	0.01		
Cp/Cv @ Oper. Cond.	1.42	1.42		
LIQUID FLOW				
Flow rate, Kg/h			1,045.00	2,500.00
Density, Kg/m3			972.50	1,009.70
Viscosity, cP			0.40	0.95
LINE (note)	ND 1.5"	ND 2"	ND 1"	ND 1.5"
Inner Diameter, inches	**1.61**	**2.16**	**0.96**	**1.61**
Length, m (note)	100.00	100.00	100.00	100.00
Roughness (std.=.00015 ft),ft	0.00	0.00	0.00	0.00
FITTING (note)				
Res. Coeff. (K)				
Note : in case of FITTING, the length must be 0 but the inner diameter and the roughness must be specified. CAUTION! K values must be corrected by the ratio: f(at calc'd Reyn.)/ f(constant at complete turbolence)				
O U T P U T				
Dens* Vel^2, kg/s^3/m^2 (<15000)	**198.37**	**255.82**	**402.86**	**275.64**
Gas density, kg/m^3	2.52	0.61	0.00	0.00
Fluid density, kg/m^3	2.52	0.61	972.50	1,009.70
Fluid viscosity, cP	0.01	0.01	0.40	0.95
Total Flow rate, kg/h	106.00	106.00	1,045.00	2,500.00
Reynold's Number	104,065.08	78,203.85	37,988.28	22,808.71
Darcy friction Factor (Fd)	0.0225	0.0222	0.0270	0.0275
Equivalent Res. Coeff.	54.91	40.55	111.27	67.16
Total Press. Drops, Psi	0.79	0.75	3.25	1.34
Press. Drops, Psi/100 ft	0.24	0.23	0.99	0.41
Fluid velocity, ft/s	29.10	67.13	2.11	1.71
Total Press.Drops, Bar	**0.0545**	**0.0519**	**0.2242**	**0.0926**
100/Dens$^{0.5}$, ft/s	252.01	512.02	-	-
Fluid velocity, m/s	**8.87**	**20.46**	**0.64**	**0.52**
Sonic Velocity, ft/s	4,338.58	4,327.03	0.00	0.00
Dens* Vel^3, kg/s^3	1,759.19	5,234.56	259.29	144.02
Flow type :	Turbulent	Turbulent	Turbulent	Turbulent