Base Load Power Hub (BLPH)

LV Cable Sizing Calculation Criteria

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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.

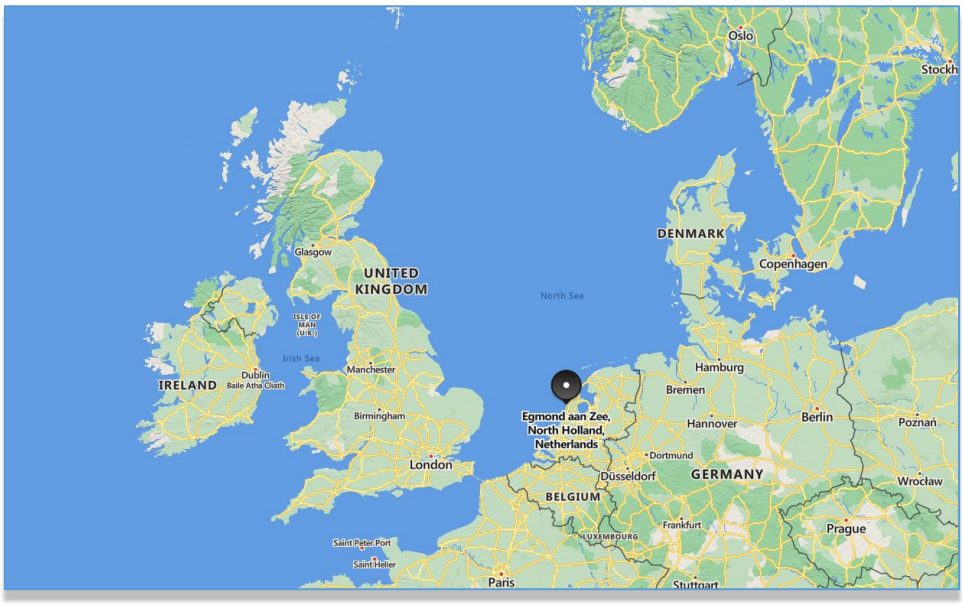


Figure 1 - HOLLANDSE KUST NOORD WIND PARK Location Map

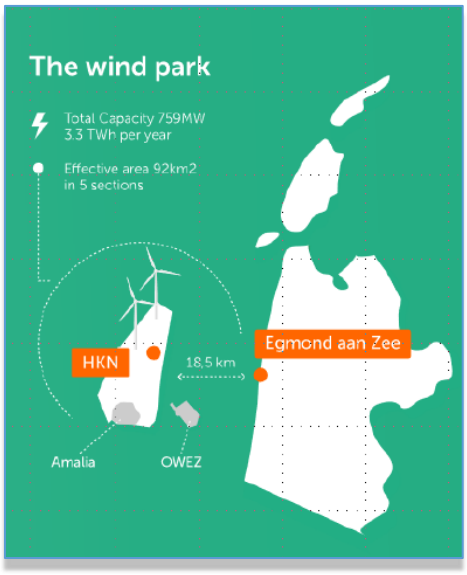


Figure 2 - Wind Park Details

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.

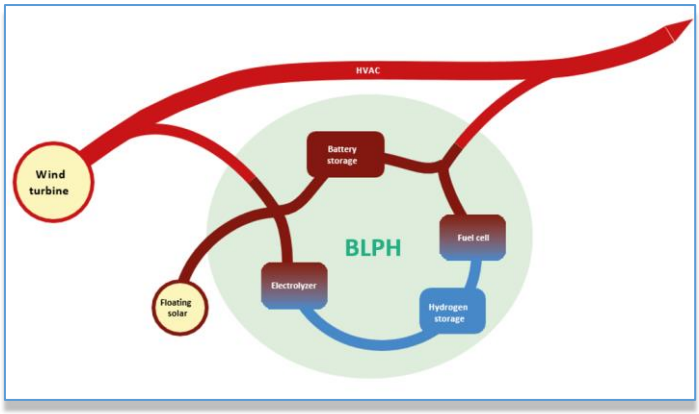


Figure 3 – BLPH Concept

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 s 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 objective of this document is to define the criteria and methods for the LV Cables Sizing Calculation for LV Distribution of BLPH.

2.1 REFERENCES

Doc. No.	Description
123A90-DDL-EL-LIS-20148	Electrical Power & Control Cable Schedule
123A90-DDL-EL-RE-20182	LV-Electrical Equipment Sizing Calculation Report
DEP 33.64.10.10	DEP Specification - Electrical Engineering Design

Table 1 - Reference Documents

2.2 DEFINITIONS AND ABBREVIATIONS

COMPANY or Client (CPY):	CROSSWIND
CONTRACTOR (CTR):	ROSETTI MARINO S.p.A.
PROJECT:	HOLLANDSE KUST NOORD WIND PARK Project
AC	Alternating Current
Cu	Copper
DC	Direct Current
KW	Kilo Watt
LV	Low Voltage
LSZH	Low Smoke Zero Halogen
N/A	Not Applicable
PF	Power Factor
SWA	Steel wire armoured
UPS	Uninterrupted Power Supply
XLPE	Cross-linked Poly Ethylene

Table 2 - Definitions and Abbreviations

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3 GENERAL CONDITIONS

3.1 LANGUAGE

All correspondence, engineering documents and manuals shall be in the English language.

4 APPLICABLE CODES AND STANDARDS

IEC - International Electro technical Committee (latest edition shall be applied).

- IEC 60502 — Power Cables with Extruded Insulation and Their Accessories for Rated Voltages from 1 kV (Um = 1.2 kV) up to 30 kV (Um = 36 kV)
- IEC 60287-1 — Electric Cables-Calculation of the current rating
- IEC 61892-4 — Mobile and fixed offshore units - Electrical installations – Cables

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5 ENVIRONMENTAL AND OPERATING CONDITIONS

The Metrological and Oceanographic Data are as given below (source: HKN2018 data @ 1979-2018)

Description	Value	Unit
Ambient Conditions		
Ambient Temperature (min/nom/max) – hourly @ +10m	-8.4 / 10.5 / 25.0	° C
Atmospheric Pressure (nominal) – hourly @ +10m	1013.7	mbar
Specific Humidity (min/nom/max) – hourly @ +10m	4.2 / 6.5 / 9.5	x 10^{-3}
Wind conditions		
Annual average wind speed (at 100m)	9.56	m/s
Extreme Wind Speed for 1-Year Recurrence Period (at 100 m)	33.1	m/s
Extreme Wind Speed for 50-Year Recurrence Period (at 100 m)	41.0	m/s
Marine conditions		
Sea Water Temperature (min/max)	1.2 / 20.2	° C
Average Sea Water Density	1025	Kg/m^3

Table 3 - Metrological and Oceanographic Data

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6 ELECTRICAL SYSTEM

The A.C. main power supply characteristics (e.g. voltage, frequency, and voltage and frequency variation) shall be defined in the relevant data sheet.

The following voltage levels shall generally be used where technically possible:

Service	Rated AC Voltage (Volts)	Phase / Wire	System Earthing
Normal LV supply	400	3ph+N+PE	Solid (TN-S)
Solar farm in-feed LV supply	800	3ph+N+PE	Solid (TN-S)
Emergency LV supply	400	3ph+N+PE	Solid (TN-S)
Low voltage distribution	400/230	3ph+N+PE/ 1ph+N+PE	Solid (TN-S)
63A welding (power) sockets	400	3ph+PE	Solid (TN-S)
Motor loads	400	3ph+PE	Solid (TN-S)
Luminaires	230	1ph+N+PE	Solid (TN-S)
Emergency luminaires	230	1ph+N+PE	Solid (TN-S)
Convenience sockets	230	1ph+N+PE	Solid (TN-S)
AC UPS	400 (In) 400/230 (Out)	3ph+N+PE 3ph+N+PE/ 1ph+N+PE	Solid (TN-S)
DC UPS	400 (In) 110 (Out)	3ph+N+PE 2+PE	Solid (TN-S)

Table 4 – System voltage levels and Earthing arrangements

7 CABLE SIZING CALCULATION CRITERIA

LV Cable Sizing is based on the following criteria and factors:

a) LV Cable Construction

b) Continuous current carrying capacity and derating factors

c) Permissible voltage drop

d) Short circuit rating verification

7.1 LV CABLE CONSTRUCTION

Single core or Multicore LV Cable type shall be Cu/XLPE/LSZH/AWA/LSZH. It is applicable for both AC & DC system.

The maximum permissible temperature limit for XLPE insulation shall be 90° C at the conductor.

7.2 CONTINUOUS CURRENT CARRYING CAPACITY AND DERATING FACTORS

The required cable current carrying capacity and derating factors shall be considered as per IEC 61892-4.

Cable ampacity:

For XLPE insulated cables, the current carrying capacities in continuous service at maximum rated conductor temperature of 90°C (ambient air temperature 45°C) shall be selected as per Table 4 of IEC 61892-4.

Derating Factors:

Correction factor for Ambient air temperature (K_1):

- For ambient air temperature of 25° C the correction factor shall be as per Table 6 of IEC 61892-4.

Correction factor for Group of cables (K_2):

- Correction factor for group of cables as specified in IEC 61892-4 paragraph 4.4.3 "for cables bunched together on cable trays, in cable conduits, pipes or trunking, unless more than six cables, which may be expected to operate simultaneously at their full rated capacity, are laid close together in a cable bunch in such a way that there is an absence of free air circulation around them. In this case, a correction factor of 0.85 should be applied."

Total derating factor $K = K_1 \times K_2$

Cables continuous current carrying capacity:

Continuous current carrying capacity of cable (I_z) = Cable ampacity x Total derating Factor (K)

Continuous current carrying capacity of cable (I_z) shall be greater than circuit breaker size (I_n) and circuit breaker size shall be greater than load current (I_b).

7.3 PERMISSIBLE VOLTAGE DROP

The voltage drop in AC cables to the end used equipment shall not exceed 5%. The voltage drop in the AC cables to the final equipment used must not exceed 5%, considering all cabling in the power circuit from the supply source to the final used equipment. During starting or reacceleration of direct on line motors, either singly or in a group, the voltage at the motor terminals shall not deviate by more than +10 % or -20 % from rated equipment voltage.

The voltage drop in DC cables shall be consistent with the minimum system voltage at the distribution board and the minimum equipment operating voltage, but should not exceed 5 % in any case.

7.4 SHORT CIRCUIT RATING VERIFICATION

Selected Cable size shall be verified for its short circuit current withstand capability, for a short circuit duration of minimum 0.2 seconds (assumed), based on the equation, $K^2 \cdot S^2 \geq I_{sc}^2 \cdot T$

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8 ANNEXES

8.1 TABLE 4 OF IEC 61892-4 – CURRENT CARRYING CAPACITIES

Table 4 – Current-carrying capacities in continuous service at maximum rated conductor temperature of 90 °C (ambient air temperature 45 °C)

Nominal cross-sectional area	Single-core	2-core	3- or 4-core
mm^2	A	A	A
1	18	15	13
1,5	23	20	16
2,5	30	26	21
4	40	34	28
6	52	44	36
10	72	61	50
16	96	82	67
25	127	108	89
35	157	133	110
50	196	167	137
70	242	206	169
95	293	249	205
120	339	288	237
150	389	331	273
185	444	377	311
240	522	444	366
300	601	511	420
	DC / AC	DC / AC	DC / AC
400	690 / 670	587 / 570	483 / 469
500	780 / 720	663 / 612	546 / 504
630	890 / 780	757 / 663	623 / 546

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8.2 TABLE 6 OF IEC 61892-4 – CORRECTION FACTOR FOR AMBIENT AIR TEMPERATURES

Table 6 – Correction factor for various ambient air temperatures (reference ambient temperature of 45 °C)

Maximum conductor temperature	Correction factors for ambient air temperatures												
°C	25 °C	30 °C	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C	70 °C	75 °C	80 °C	85 °C
90	1,20	1,15	1,10	1,05	1,00	0,94	0,88	0,82	0,74	0,67	0,58	0,47	-
95	1,18	1,14	1,10	1,05	1,00	0,95	0,89	0,84	0,77	0,71	0,63	0,55	0,45

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8.3 CABLE MANUFACTURER CATALOGUE

All cable designs covered in this publication generally conform to BS 5467 or IEC 60502 Part-1 for XLPE and BS 6346 or IEC 60502 Part-1 for PVC insulated cables suitable for working voltages 600/1000 Volts and 3300 Volts.

A.C. RESISTANCE AND REACTANCE VALUES FOR XLPE INSULATED CABLES

Nominal Cross-sectional area of conductor	XLPE Insulated Cables (600/1000 V Grade)						
	A.C Resistance at 90 °C				Reactance at 50 Hz		
	Single Core Cables		Multi Core Cables		Single Core Cables		Multi Core Cables
	Copper	Aluminium	Copper	Aluminium	Armoured	Unarmoured	
mm²	Ohm/km		Ohm/km		Ohm/km		Ohm/km
1.5	15.43	-------	15.43	-------	-------	0.147	0.105
2.5	9.45	-------	9.45	-------	-------	0.137	0.099
4	5.88	-------	5.88	-------	-------	0.128	0.093
6	3.93	-------	3.93	-------	-------	0.119	0.089
10	2.33	-------	2.33	-------	-------	0.111	0.084
16	1.47	2.45	1.47	2.45	-------	0.103	0.081
25	0.927	1.54	0.927	1.54	-------	0.103	0.081
35	0.668	1.11	0.669	1.11	-------	0.098	0.079
50	0. 494	0.822	0.494	0.822	0.114	0.093	0.078
70	0.342	0.568	0.343	0.569	0.106	0.088	0.074
95	0.247	0.411	0.248	0.411	0.102	0.086	0.072
120	0.196	0.325	0.197	0.326	0.097	0.085	0.072
150	0.160	0.265	0.160	0.265	0.099	0.085	0.073
185	0.128	0.212	0.129	0.212	0.095	0.083	0.072
240	0.0990	0.162	0.100	0.163	0.093	0.082	0.071
300	0.0805	0.130	0.0815	0.131	0.092	0.079	0.071
400	0.0645	0.102	0.0660	0.103	0.090	0.080	0.070
500	0.0525	0.0815	-------	-------	0.089	0.078	-------
630	0.0430	0.0650	-------	-------	0.087	0.078	-------
800	0.0365	0.0530	-------	-------	0.086	0.076	-------
1000	0.0320	0.0445	-------	-------	0.085	0.075	-------

9 CABLE SIZING CALCULATIONS

Cable sizing calculations are carried out using the following equations

9.1 LEGEND

Symbol	Description
E	Efficiency of load
I_a	Cable ampacity refer Table-4 of IEC-61892-4
I_b	Load current
I_n	Circuit Breaker size
I_{sc}	Short Circuit Current in Kilo Amperes
I_z	Continuous current carrying capacity of cable after derating
K	Constant for XLPE insulated Copper Conductor (value = 0.143)
K_1	Temperature correction factor refer Table-6 of IEC-61892-4
K_2	Cable Grouping correction factor refer IEC-61892-4 Paragraph-4.4.3
K_d	Total derating factor
K_{sT}	Motor Starting Current multiple of full load current (only for Motor feeders)
L	Cable route length in meters
N	Number of Runs per Phase
P	Power in kilowatts
R	AC Resistance of conductor at 90°C in Ω / km
S	Size of the conductor in mm^2
T	Short Circuit withstand time
V_D	Voltage Drop in Volts
V_S	System Voltage in Volts (different level of voltages like 800V, 400V, 230V, 110V)
X	Reactance at 50 HZ in Ω / km
ϕ	Power factor
ϕ_{sT}	Power factor Angle at Motor Starting
ϕ_{FL}	Power factor Angle at Full Load

Table 5 – Legend

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9.2 CONTINOUS CURRENT CARRYING CAPACITY AND DERATING FACTORS

To verify the Cable continuous current carrying capacity as following equation: $I_b \leq I_n \leq I_z$

$I_b = P / \sqrt{3} \times V_S \times \phi \times E$

$I_z = I_a \times K_d$

$K_d = K_1 \times K_2$

9.3 PERMISSIBLE VOLTAGE DROP

The permissible voltage drop considered is $V_D\% < 5\%$, considering all cabling in the power circuit from the supply source to the final used equipment. Starting from the cable resistance and reactance values, the voltage drop is given by:

Motor Feeder during Starting (V_D) $= [\sqrt{3} \times I_b \times L \times K_{sT} \times (R \cos\phi_{sT} + X \sin\phi_{sT})] / 1000 \times N$

Three Phase Load (V_D) $= [\sqrt{3} \times I_b \times L \times (R \cos\phi_{FL} + X \sin\phi_{FL})] / 1000 \times N$

Single Phase Load (V_D) $= [2 \times I_b \times L \times (R \cos\phi_{FL} + X \sin\phi_{FL})] / 1000 \times N$

DC Load (V_D) $= [2 \times I_b \times R \times L] / 1000 \times N$

Percentage of Voltage Drop ($V_D\%$) $= [V_D \times 100] / V_S$

9.4 SHORT CIRCUIT RATING VERIFICATION

To verify the Cable short circuit current rating as following equation: $K^2 \cdot S^2 \geq I_{sc}^2 \cdot T$

9.5 VALIDATION CABLE SIZING CALCULATION – THREE PHASE LOAD

Cable from 400V LV Switchboard SG-200N1 to Instrument Air Package A-63000

Instrument air package Incoming cable type is Cu/XLPE/ LSZH/AWA/LSZH and cable data's given below:

S = 4C x 4 mm^2

R = 5.88 Ω /km

X = 0.093 Ω /km

a) Continuous Current carrying capacity

To Verify $I_b \leq I_n \leq I_z$

I_n = 16A

$I_b = P / \sqrt{3} \times V_S \times \phi \times E$

P = 5.5kW

V_S = 400V

ϕ = 0.9

E = 0.95

I_b = 9.28A

$I_z = I_a \times K_d$

$K_d = K_1 \times K_2$

I_a = 28A

K_1 = 1.20

K_2 = 0.85

K_d = 1.02 (derating factor shall be consider as 1 if calculated value >1)

I_z = 28 x 1

I_z = 28A

9.28A < 16A < 28A

Continuous current carrying capacity of the cable is verified.

b) Check for Voltage drop

To Verify $V_D\% < 5\%$

$V_D = [\sqrt{3} \times I_b \times L \times (R \cos\phi_{FL} + X \sin\phi_{FL})] / 1000 \times N$

L = 60 m

N = 1

Vs = 400

$V_D = [\sqrt{3} \times 9.28 \times 60 \times (5.88 \times 0.9 + 0.093 \times 0.44)] / [1000 \times 1]$

V_D = 5.15 V

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$V_D\%$ = [V_D x 100] / Vs

$V_D\%$ = [5.15 x 100] / 400

$V_D\%$ = 1.29%

LV Switchboard SG-200N1 to Instrument Air Package $V_D\%$= 1.29%

6.6/0.415 kV Transformer TR200DE1 to LV Switchboard SG-200N1 $V_D\%$= 0.40%

Total Summary $V_D\%$ = 1.29 % + 0.40% =1.69 %

Total Voltage drop $V_D\%$ = 1.69% < 5%

Voltage drop during at maximum load is less than the permissible voltage drop of 5%.

c) Short circuit rating verification

To Verify $K^2 \cdot S^2 \geq Isc^2 \cdot T$

K = 0.143

S = 4 mm^2

I_{sc} = 2.092 kA (from ETAP report)

T = 0.01 sec (assumed)

$(0.143)^2 \times (4)^2 \geq (2.092)^2 \times 0.01$

0.327 > 0.0437

Short circuit rating of the cable is within the limit. Hence, the selected cable 4C x 4 mm^2 is adequate.

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9.6 VALIDATION CABLE SIZING CALCULATION – SINGLE PHASE LOAD

Cable from AC UPS – PAS DB to Field Instrument Panel

Instrument air package Incoming cable type is Cu/XLPE/ LSZH/AWA/LSZH and cable data's given below,

S = 3C x 10 mm^2

R = 2.33 ohm/km

X = 0.084 ohm/km

a) Continuous Current carrying capacity

To Verify $I_b \leq I_n \leq I_z$

I_n = 32A

$I_b = P / V_S \times \phi \times E$

P = 5kW

V_S = 230V

E = 1.0

ϕ = 0.8

I_b = 27.17A

$I_z = I_a \times K_d$

$K_d = K_1 \times K_2$

I_a = 50A

K_1 = 1.20

K_2 = 0.85

K_d = 1.02 (derating factor shall be consider as 1 if calculated value >1)

I_z = 50 x 1

I_z = 50A

27.17A < 32A < 50A

Continuous current carrying capacity of the cable is verified.

b) Check for Voltage drop

To Verify $V_D\% < 5\%$

V_D = $[2 \times I_b \times L \times (R \cos\phi_{FL} + X \sin\phi_{FL})] / 1000 \times N$

L = 30 m

N = 1

V_S = 400V

V_D = $[2 \times 27.17 \times 30 \times (2.33 \cos 0.8 + 0.084 \sin 0.6)] / [1000 \times 1]$

V_D = 1.56 V

$V_D\%$ = $[V_D \times 100] / Vs$

$V_D\%$ = $[1.56 \times 100] / 400$

$V_D\%$ = 0.68% < 5%

6.6/0.415 kV Transformer TR200DE1 to LV Switchboard SG-200N1 $V_D\%$= 0.40%

LV Switchboard SG-200N1 to AC UPS PAS UP-200E3 $V_D\%$= 0.59%

AC UPS PAS UP-200E3 to Field Instrumentation Panel $V_D\%$= 0.68%

Total Summary $V_D\%$ = 0.40 % + 0.59% + 0.68% = 1.67 %

Total Voltage drop $V_D\%$ = 1.67% < 5%

Voltage drop during at maximum load is less than the permissible voltage drop of 5%.

c) Short circuit rating verification

To Verify $K^2 \cdot S^2 \geq Isc^2 \cdot T$

K = 0.143

S = 10 mm^2

I_{sc} = 5.135 kA (from ETAP report)

T = 0.01 sec (assumed)

$(0.143)^2 \times (10)^2 \geq (5.135)^2 \times 0.01$

2.045 > 0.264

Short circuit rating of the cable is within the limit. Hence, the selected cable 3C x 10 mm^2 is adequate.

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