Base Load Power Hub (BLPH)

Electrical Protection Relay Selectivity Study Report

Document Number: 123A90-DDL-EL-RE-20168

Document Class: 2

03	23/09/2025	As-Built (ASB)	SPS	LMA-AMA	CGI
02	02/09/2024	Approved for Construction (AFC)	SPU	LMA-AMA	MDO
01	08/08/2024	Approved for Construction (AFC)	SPU	LMA-AMA	MDO
00	19/06/2024	Issue for Review (IFR)	SPU	LMA-AMA	MDO
Rev.	Date	Description	Prepared	Reviewed	Approved

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Revision / Change Log

Rev.	Description
00	Issue for Review (IFR)
01	Approved for Construction (AFC)
02	Approved for Construction (AFC)
03	As-Built (ASB)

HOLDS LIST

No.	Description

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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.

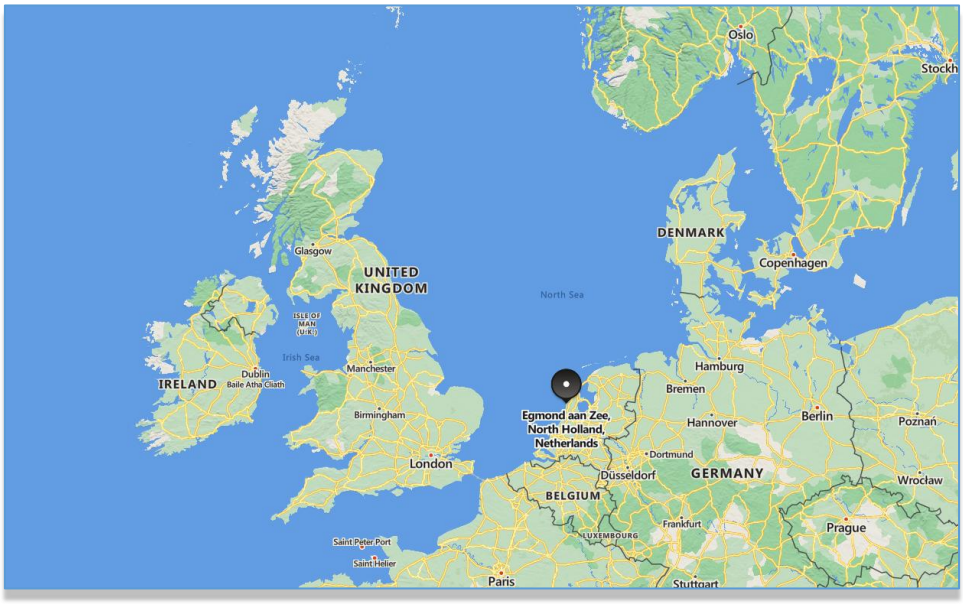


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

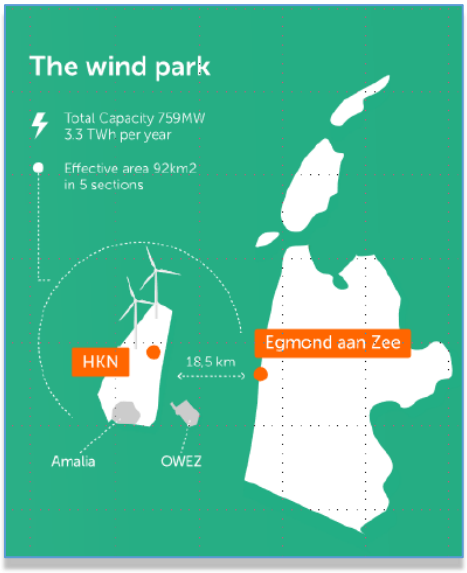


Figure 2 - Wind Park Details

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.

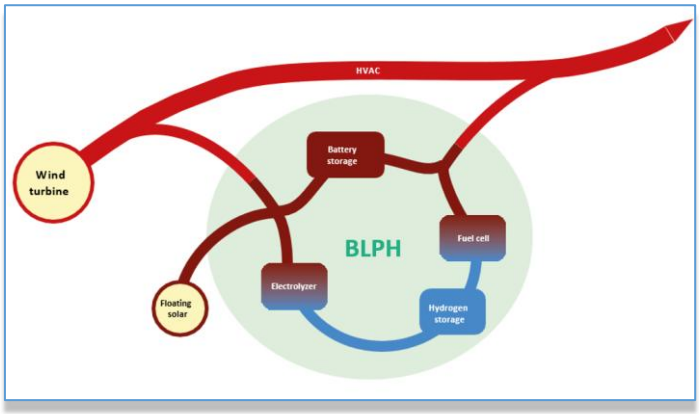


Figure 3 – BLPH Concept

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 purpose of this document is to determine the appropriate settings for the protection relays in the BLPH system.

Basically, the protective system design is based on the knowledge that the faults or abnormal operating conditions can be led to:

- overloads;
- ground faults;
- phase to phase and three phase faults.

The detection of the above conditions is undertaken by the protective relays, whose task is to shut down the faulted part from operation and separate it from the electrical distribution system. The settings of the relays have been selected in order to allow a reliable operation of the system, keeping as long and as much as possible the feeders or the system in service without risk of damage. Settings are fairly above any transient current, voltage, frequency conditions, and operating times allow for the recovery of the electrical parameters within their normal operating values.

2.1.1 Study Organization

This document has been subdivided in several sections.

At the beginning, some general information about the system and a summarized description of the protection system are presented.

Main criteria for relay settings are then described.

The section relevant to the selectivity analysis is subsequently presented, with the following main subsections:

Main Equipment Data

The main equipment data for relay coordination are presented in these schedules. The indicated values are the following:

- transformers: rated power, primary and secondary rated voltage, connection type, short circuit impedance, X/R ratio, secondary side grounding resistance value (if applicable);
- motors: rated power, rated voltage, rated current, starting current at rated voltage and at 80% of rated voltage, starting time at rated voltage and at 80% of rated voltage, locked rotor time capability (cold and hot values), CT ratio.

Setting Calculation for Differential Relays

In this subsection, setting calculation for differential relays are presented.

One Line Diagrams

The one-line diagrams show in a simplified form the electrical network as well as the point of installation of the main relays being part of the protective system.

The relays are identified by the ANSI Standard code number or by their graphic symbol.

All the relays that must be coordinated are identified with a number to allow an easy identification in the setting tables and coordination sheets.

Setting Tables

The setting ranges and values of the primary and secondary protections are defined into the setting tables. The sequence used to group all the tables is in accordance with the switchboard code numbering. Into the column's "function", "page", "numbers", the code number of the relays, the pages where the coordination curves are drawn and the labels of the relevant curves are indicated.

Selectivity Curves

The selectivity curves section includes the plots of the curves that are significant for the relay coordination.

The curves detail and demonstrate protective relays setting/coordination. For direct acting protections, the time takes into account the operating time of the circuit breaker, while for indirect relay, the indicated time is related only to the relay operating time: opening time of the circuit breaker shall be added to obtain the total clearing time.

In the selectivity curves sheets, the following relevant points (landmarks) are indicated:

- short circuit current values;
- transformers FLA, inrush current point and capability points according to ANSI C57;
- maximum foreseen feeder "reacceleration" current IREAX;
- a little vertical line in the superior part of the page is drawn in correspondence of the setting value of inverse type relays.

IREAX current is intended to be the peak feeder (MCC or SG) loading current, under largest motor starting conditions or motors reacceleration conditions. The time during which the feeder loading current is assumed equal to IREAX is related to motor starting time.

2.1.2 System Analysis Software

To perform these network calculations, ETAP PowerStation Version 22.5.0 by OTI has been used.

2.2 REFERENCES

Doc. No.	Description
123A90-DDL-EL-DG-20158 Rev. 1	Overall Single Line Diagram
123A90-PML-PM-TQ-00033	Technical Query – Electrical data of WTG-57
123A90-DDL-EL-RE-20171 Rev. 1	Electrical System Study Report – Short Circuit
1723002197-EL-DG-00010	Electrical Single Line Diagram for SG-100D1
BASE LOAD POWER HUB (BLPH) 66kV_2024.06.04	66kV Switchgear (GIS) - Circuit and Wiring Diagram
1723002197-EL-DG-00011 Rev.02	Electrical Single Line Diagram for SG-200N1
1723002197-EL-DG-00015	Functional Diagram Incoming Feeder TR-100AD1
1723002197-EL-DG-00016	Functional Diagram Bus Bar Metering
1723002197-EL-DG-00017	Functional Diagram BESS Feeder A-85000
1723002197-EL-DG-00018	Functional Diagram ELECTROLYSER Feeder A-20000
1723002197-EL-DG-00019	Functional Diagram FUEL CELL Feeder A-80000
1723002197-EL-DG-00020	Functional Diagram Transformer Feeder TR-200ED1
1723002197-EL-DG-00021	Functional Diagram Transformer Feeder TR200DE1
123A90-DDL-EL-DG-20014 Rev. 1	Electrical Control, Protection and Metering Diagram

Table 1 - Reference Documents

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2.3 DEFINITIONS AND ABBREVIATIONS

BESS	Battery Energy Storage System
BLPH	Base Load Power Hub
COMPANY or Client (CPY):	Crosswind
CONTRACTOR (CTR):	ROSETTI MARINO S.p.A.
CT	Current Transformer
FLA	Full Load Ampere
HV	High Voltage
KNAN	Non mineral oil natural Air Natural
LV	Low Voltage
MV	Medium Voltage
N/A	Not Applicable
NER	Neutral Earthing Resistor
OCTC	Off Circuit Tap Changer
OLTC	On Load Tap Changer
PROJECT:	HOLLANDSE KUST NOORD WIND PARK Project
SCC	Short Circuit Current
SLD	Single Line Diagram
TCC	Time Current Curve
U_k	Short-circuit impedance
VT	Voltage Transformer
WTG	Wind Turbine Generator
CPI	Company Provided Items (i.e. BESS, Electrolyser, Fuell Cell and Solar packages)

Table 2 - Definitions and Abbreviations

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3 DESIGN BASIS

This section presents the details of all the input data, as well as assumptions used for the system studies for BLPH.

3.1 SYSTEM OVERVIEW

The system studied in this report is based on the single line diagram, 123A90-DDL-EL-DG-20158 Rev. 1. The WTG-57 is the wind turbine being connected to the BLPH. It is connected to the rest of the Crosswind offshore windfarm at the end of string A at a 66 kV busbar. The BLPH is also connected to this busbar via a 66/6.9 kV transformer. At the BLPH 6.6 kV BLPH busbar the BESS, electrolyser, fuel cell and solar farm is connected. There is also a 6.6/0.42 kV transformer supplying different loads at the BLPH.

3.2 MODEL OVERVIEW

WTG-57 is connected to the Crosswind offshore windfarm, via string A. WTG-57 is at the end of this string A.

BLPH is connected to the Crosswind offshore windfarm at the common 66 kV busbar with the WTG-57.

At this 66 kV busbar, the rest of the components in the string A is modelled as the supply network. This is termed as "windfarm" in the model.

Other electrical components connected to this 66 kV busbar, 6.6 kV busbar and 400 V busbar are in accordance with the single line diagram in 123A90-DDL-EL-DG-20158 Rev. 1, as well as datasheets of transformers.

Data provided in the single line diagram 123A90-DDL-EL-DG-20158 Rev. 1 were used to model these transformers.

3.3 ANALYSIS DESIGN DATA

In the following paragraphs, a brief summary of BLPH Platform main equipment data is presented.

More details are available in the attached ETAP calculations reports.

3.3.1 Supply network

ITEM	3-PH SCC Max [kA]	X/R	3-PH SCC Min [kA]	X/R [pu]
66kV Network 3Ph	15.5	10.0	8.7	10.0
66kV Network 1Ph	7.10	10.0	6.3	10.0

Table 3 - Data for External Network

3.3.2 Power Sources

ITEM	Rated Power [kVA]	Vn [kV]	In [A]	Maximum Generated Active Power [kW]	Sustained SCC [% In]
A-85000 BESS package	1250.0	6.6	109.3	1000.0	150.0
A-80000 Fuel cell package	1250.0	6.6	109.3	1000.0	150.0
PV_Plant	660.0	0.8	476.3	480.0	100.0

Table 4 - Data for Internal Power Sources

3.3.3 Transformers

ITEM	An [kVA]	V1n/V2n [kV]	I1n/I2n [A]	Zcc [%]	X/R [pu]	Vector Group
TR-100AD1	7000.0	66.0+/-8x1.25%/0.69	61.2/585.7	8.0	16.01	Dyn11
TR-200DE1	1600.0	6.6/0.42	139.9/2199.5	6.0	7.94	Dyn11
TR-200ED1	500.0	6.6/0.8	43.7/360.8	6.0	7.63	Dyn11

Table 5 - Data for Main Transformers

3.3.4 Switchgear Data

ITEM	Rated Voltage [kV]	Rated Ampacity [A]	Short Circuit Rating [kA - s]
HNA6-AFA70	66.0	1250.0	31.5 - 1s
SG-100D1	6.6	630.0	25.0 – 1s
SG-200N1	0.4	2500.0	50.0 – 1s

Table 6 – Data for Main Switchgears

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3.4 SHORT CIRCUIT CURRENTS

The following table summarizes the maximum and minimum short circuit values, as per 123A90-DDL-EL-RE-20171 Rev. 1 - Electrical System Study Report – Short Circuit.

ITEM	Rated Voltage [kV]	Ph-Ph SCC-Max [kA]	PH-G SCC-Max [kA]	Ph-Ph SCC-Min [kA]	PH-G SCC-Min [kA] (*)	PH-PH Through Fault Current [kA]
HNA6-AFA70	66	14.76	6.71	7.30	5.97	--
SG-100D1	6.6	8.11	0.4	5.08	0.4	--
TR-100AD1	6.9	8.11	0.4	5.08	0.4	7.67
SG-200N1	0.4	31.35	33.52	18.76	6.58	--
TR200DE1	0.4	31.35	33.52	18.76	6.58	30.36

Table 7 - Data for Short Circuit Current

(*) In order to consider the arc fault resistance in LV system, the L-G Minimum SCC has been calculated as follows: Icc PH-G_min = Icc 3PH_min x 0.28

4 RELAY COORDINATION STUDY

4.1 PROTECTION SYSTEM DESCRIPTION

The protective relays undertake the detection of abnormal conditions, whose task is to shut down the faulted part from the operation and separate it from the electrical distribution system. The setting of the relays has been selected to allow a reliable operation of the system, keeping as long and as much as possible the feeders or the system in service without risk of damage.

Two different kinds of protective devices have been used for protection of the electrical system:

- thermal overload relays and electronic built-in overcurrent and ground fault releases for low voltage distribution.
- secondary relays fed from CTs and VTs for overcurrent and short circuit protection and ground fault protection, for low and high voltage level.

For the indirect relays, the microprocessor technology has been used; the protection functions which have been considered active in the multifunction relays are indicated in the setting tables and in the one-line diagrams.

Network protections are schematically shown in the simplified one-line diagrams, by using ANSI code numbers or graphic symbols (LV equipment).

4.2 ISLAND OPERATION MODE

To assure the best protection level in case of island operation, dedicated thresholds have been considered to be activated only in that case. The REX640 protection relay installed on the 6.6 kV incoming cubicle has to detect the island and send a signal on the IEC 61850 network so that all the other protection relays of the same switchgear and on the LV income protection can activate the relevant settings.

With respect to the phase-to-ground fault, the 6.6 kV system is ungrounded when on the island, so it will be detected by means of the residual overvoltage protection (59N), which has been set to trip first the feeders to the solar package and then the one to the fuel cells. The BESS feeder will be tripped as the last one since it means losing the auxiliary transformer TR-200DE1 feeder.

4.3 SETTING CRITERIA

4.3.1 LV Feeders

Generally, thermal unit shall be set above maximum service current, while magnetic unit shall consider operating conditions and coordination with downstream circuit breakers, considering a minimum value of five time of maximum service current.

4.3.2 LV Transformer Incoming

Two phase overcurrent units have been used:

- Low level: inverse time curve; pick-up equal to about incoming transformer FLA and time multiplier chosen to achieve selectivity with downstream protection.

- High level (when suitable): definite time curve; pick-up above 1.2 times the downstream protections high level value. To assure selectivity, a grading margin of at least 200ms with tie breaker protection shall be chosen.

One residual earth overcurrent unit has been used:

- Low level: inverse time curve; the minimum pick-up value is 0.1 CT primary current and time multiplier chosen to achieve selectivity with downstream protection. To assure selectivity, a grading margin of at least 200ms with downstream protection shall be chosen.

4.3.3 Star Point of HV/LV Transformer

Star point earth overcurrent unit has been used:

- Low level: inverse time curve; pick-up equal to about 1.2 times the incoming protection value. To assure selectivity, a grading margin of at least 200ms with downstream protection.

4.3.4 HV/LV Transformer Feeders

Three phase overcurrent units have been used:

- Low level: dependent time curve; pick-up equal to about 1.4 transformer FLA and time multiplier chosen to achieve selectivity with downstream protection and assure transformer protection according to transformer capability curve.
- First high level (when suitable): definite time curve; pick-up above high level of LV incoming protection, referred to primary side. To assure selectivity, a grading margin of about 200ms with downstream protection shall be chosen.
- Second high level: instantaneous time curve; pick-up above 1.3 times the secondary short circuit level or the inrush current, whatever is the higher, in order to take into account current asymmetry. To assure selectivity with Fuse, a grading margin is considered.

One earth overcurrent protection unit has been used:

- Low level: definite time curve; pick-up equal to about 0.1 CT primary current and time delay equal to 100ms.

4.3.5 HV Package Feeders (CPI)

CPI suppliers are responsible for the setting of their internal protection, taking into account the data indicated in the present study, to have a selective behaviour with upstream the HV protections.

Two overcurrent units have been used:

- Low level: dependent time curve; pick-up equal to about 1.2 maximum service current and time multiplier chosen to achieve selectivity with downstream protection, if any.

- First high level (when suitable): definite time curve; pick-up equal to about 2.5 maximum service current. The minimum time delay has been calculated to assure the selectivity between the fuse and the maximum breaking current of the contactor.

One earth overcurrent protection unit has been used:

- Low level: definite time curve; pick-up equal to about 0.1 CT primary current and time delay equal to 100ms.

4.3.6 HV/HV Transformer Incoming

Two phase overcurrent units have been used:

- Low level: inverse time curve; pick-up equal to about incoming transformer FLA and time multiplier chosen to achieve selectivity with downstream protection.
- High level (when suitable): definite time curve; pick-up above 1.2 times the downstream protections high level value. To assure selectivity, a grading margin of at least 200ms with tie breaker protection shall be chosen.

One residual earth overcurrent unit has been used:

- Low level: definite time curve; pick-up above 1.2 times the downstream protections high level value. To assure selectivity, a grading margin of at least 200ms with tie breaker protection shall be chosen.

4.3.7 Star Point of HV/HV Transformer

Star point earth overcurrent unit has been used:

- Low level: definite time curve; pick-up above 1.2 times the downstream protections high level value. To assure selectivity, a grading margin of at least 200ms with tie breaker protection shall be chosen.

4.3.8 HV/HV Transformer Feeders

- The TR-100AD1 is protected by differential relay. For all type of faults, this protection assures an intrinsically selective behavior, thus it can operate instantaneously. In this case, other protections assure the back-up function.
- Mixed current and time selectivity assures protection coordination.

Three overcurrent units have been used:

- Low level: dependent time curve; pick-up equal to about 1.4 transformer FLA and time multiplier chosen to achieve selectivity with downstream protection and assure transformer protection according to transformer capability curve for infrequent faults.

- First high level (when suitable): definite time curve; pick-up above high level of MV incoming protection, referred to primary side. To assure selectivity, a grading margin of about 200ms with downstream protection shall be chosen.
- Second high level: instantaneous time curve; pick-up above 1.3 times the secondary short circuit level or the inrush current, whatever is the higher, in order to take into account current asymmetry.

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4.3.9 Setting Calculation for Transformer Differential Protection (87T) and Restricted Ground Fault Protection (64REF)

TR-100AD1 – 7MVA – 66/6.9kV – 61.23/585.72 transformer differential (87T) protection

Differential relay SIEMENS 7UT85

- HV 66kV CT = 250/1
- MV 6.9kV CT = 600/1
- Transformer Starpoint CT = 250/1
- The transformer group is Dyn11.

PERCENT DIFFERENTIAL PICKUP: This setting defines the minimum differential current required for operation. It is chosen, based on the amount of differential current that might be seen under normal operating conditions. Two factors may create differential current during the normal transformer operation: errors due to CT inaccuracies and current variation due to onload tap changer operation.

Percent Differential: Pickup proposed setting = 20%

PERCENT DIFFERENTIAL SLOPE 1: This setting defines the differential restraint during normal operating conditions to assure sensitivity to internal faults. The setting must be high enough, however, to cope with CT saturation errors during saturation under small current magnitudes but significant and long-lasting DC components (such as during distant external faults in vicinity of generators).

Percent Differential: Slope 1 proposed setting = 30%

INTERSECTION 2: The settings for Intersection 2 depend very much on the capability of CTs to correctly transform primary into secondary currents during external faults. Intersection 2 should be set below the fault current that is most likely to saturate some CTs due to an AC component alone.

Is2: proposed setting = 2.0 pu

PERCENT DIFFERENTIAL SLOPE 2: The slope 2 setting ensures stability during heavy through fault conditions, where CT saturation results in high differential current. Slope 2 should be set high to cater for the worst case where one set of CTs saturates but the other set doesn't. In such a case the ratio of the differential current to restraint current can be as high as 95 to 98%.

Percent Differential: Slope 2 setting is chosen equal to 75%.

Other setting as indicated in the relevant Setting Table.

Restricted ground function settings: the setting for the Is1 thresholds is 10-25% of the minimum earth fault current for a fault at the transformer terminals when resistance earthed. In this case, it has been chosen 24% (60 A). As per Siemens manual the recommended setting for the slope is 7%, in order to avoid spurious tripping has been set to 10%.

Regarding the time delay, the chosen setting is 0.1 s.

4.4 COMMENTS ON SELECTIVITY STUDY

The selective behaviour of the protections is assured in any service condition, both for phase and for ground faults.

In the setting tables, the main setting of the multifunction relays is detailed. The use of output contacts, latched function, etc. must be chosen according to wiring diagrams.

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5 ATTACHMENTS

- Attachment A: Simplified Single Line Diagrams.
- Attachment B: Setting Tables.
- Attachment C: Time Current Curve (TCC) printout.