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Short-Term Post Fault Rating Technical Specification and Risk Assessment

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Contents

1. Introduction

This document provides a functional specification for the short-term post-fault rating (STPFR) of overhead line (OHL) conductors based on real-time reported conductor temperature measurements.

This document builds on the high-level technical implementation of STPFR delivered under the Overhead Line Power Pointer project to determine the post-fault rating of OHL conductors based on real-time reported conductor temperature measurements. This was trialled in a non-live operational environment as part of OHL Power Pointer.

The method builds on the work published by CIGRE in the Technical Brochure 601, Part E.3 ‘Temperature Tracking Calculation’ which provides an example for continuously predicting conductor temperature using a set of heat balance equations.

This technical specification will build on the following:

- A review of conductor characteristics used in the thermal model (to extend the subset of conductors used in OHL Power Pointer to a full set of conductors used by WPD across our network).
- A review of WPD’s OHL policies to ensure conformity with current practices (e.g., SD8A – relating to the revision of OHL ratings).
- Specifying the frequency of the STPFR calculation, the interval between routine conductor temperature monitoring from the OHL solution (review of input parameters of the algorithm to align with control room requirements) to feed into the technical specification.
- A risk assessment to identify and evaluate any potential risks of the application of (deterministic) short-term post-fault ratings to OHL systems.

The post-fault rating function is most useful for overhead lines carrying large currents, where line current results in noticeable heating of the conductor above ambient temperature.

2. Conductor Characteristics Review

2.1. Specifying Conductor Characteristics

In order for conductors to be utilised within the STPFR solution, the following characteristics need to be specified:

Conductor Type	175mm2 Lynx ACSR
Construction Type	ACSR
Conductor Outside Diameter (mm)	19.53
Core Diameter (mm)	8.37
Outer Strand Diameter (mm)	2.79
Total Area (mm^2)	226.2
Emissivity	0.8
Solar Absorptivity	0.8
Conductor AC Resistance at 25°C (Ω/km)	0.16078
Conductor AC Resistance at 75°C (Ω/km)	0.19745
Steel Mass per Unit Length (kg/m)	0.335
Aluminium Mass per Unit Length (kg/m)	0.507
Total Mas per unit length (kg/m)	0.842

2.2. Conductor Characteristic Tables Based on OHL Policies

58 different conductor types are included in SD8A. High and medium priority conductor types have been selected following discussions with WPD.

Conductor Type	Code Name	Priority
300 mm2 Upas (37/3.53mm) AAAC AL5	Upas	HIGH
500 mm2 Rubus (61/3.50mm) AAAC AL5	Rubus	HIGH
570 mm2 Sorbus (61/3.71mm) AAAC AL5	Sorbus	HIGH
700 mm2 Araucaria (61/4.14mm) AAAC AL5	Araucaria	HIGH
175 mm2 Lynx (30/2.79mm + 7/2.79mm) ACSR	Lynx	HIGH
400 mm2 Zebra (54/3.18mm + 7/3.18mm) ACSR	Zebra	HIGH
100 mm2 Oak (7/4.65mm) AAAC AL5	Oak	MEDIUM
150 mm2 Ash (19/3.48mm) AAAC AL5	Ash	MEDIUM
175 mm2 Elm (19/3.76mm) AAAC AL5	Elm	MEDIUM
200 mm2 Poplar (37/2.87mm) AAAC AL5	Poplar	MEDIUM
250 mm2 Sycamore (37/3.23mm) AAAC AL5	Sycamore	MEDIUM
150 mm2 Hornet (19/3.25mm) AAC AL1	Hornet	MEDIUM
250 mm2 Cockroach (19/4.22mm) AAC AL1	Cockroach	MEDIUM
300 mm2 Butterfly (19/4.65mm) AAC AL1	Butterfly	MEDIUM
400 mm2 Centipede (37/3.78mm) AAC AL1	Centipede	MEDIUM
100 mm2 Dog (6/4.72mm + 7/1.57mm) ACSR	Dog	MEDIUM
150 mm2 Dingo (18/3.35mm + 1/3.35mm) ACSR	Dingo	MEDIUM
175 mm2 Caracal (18/3.61mm + 1/3.61mm) ACSR	Caracal	MEDIUM
200 mm2 Jaguar (18/3.86mm + 1/3.86mm) ACSR	Jaguar	MEDIUM
70 mm2 (7/3.55mm) HDC		MEDIUM
100 mm2 (7/4.30mm) HDC		MEDIUM
125 mm2 (19/2.90mm) HDC		MEDIUM
150 mm2 (19/3.20mm) HDC		MEDIUM

3. STPFR Calculation Methodology

3.1. Introduction

This section outlines the calculation methodology for STPFR builds on the work published by CIGRE in the Technical Brochure 601, Part E.3 ‘Temperature Tracking Calculation’.

This is structured in the following way:

- Conductor Parameters
- Algorithm
  - Determine Temperature Time Step
  - Derive Temperature Series
  - Data Conditioning

3.2. Conductor Parameters

The characteristics for a particular conductor type are given in section 2.

<u>Example</u>

Conductor “175mm2 Lynx ACSR” rated temperature 50°C
Type = “ACSR”
Resistance @ 25°C = “0.161286”
Resistance @ 75°C = “0.192958”
Steel Mass / Unit length = “0.335”
Aluminium Mass/ Unit Length = “0.507”
Total Mass / Unit Length = “0.842”

3.3. Algorithm

3.3.1. Determine Temperature Step

The maximum rise in temperature of the conductor over the (user definable period) is split into 10 x ∆T ‘steps’
Determine the temperature step:

$$\Delta T = \frac{T_{max} - T_{live}}{Period}$$

<u>Example</u>

Conductor “175mm2 Lynx ACSR” rated temperature 50°C, present temperature 17.5°C, period 10 minutes

$$\Delta T = \frac{50 - 17.5}{10} = 3.25°C$$

3.3.2. Derive Temperature Series

Create a series of temperatures intervals of the temperature step

Example

Conductor “175mm2 Lynx ACSR” rated temperature 50°C, present temperature 17.5°C,

T_{series}
17.500
20.750
24.000
27.250
30.500
33.750
37.000
40.250
43.500
46.750

3.3.3. Determine Mass x Heat Capacity

For ACSR:

$$mc = m_{alu} \cdot c_{alu} \cdot (1 + \beta_{alu} \cdot T_{series} - 20) + m_{steel} \cdot c_{steel} \cdot (1 + \beta_{steel} \cdot T_{series} - 20)$$

Where β is the temperature coefficient of specific heat capacity.

For Copper:

$$m \cdot c = m_{cu} \cdot c_{cu} \cdot (1 + \beta_{cu} \cdot T_{series} - 20)$$

For All Aluminium (AAC & AAAC):

$$m \cdot c = m_{alu} \cdot c_{alu} \cdot (1 + \beta_{alu} \cdot T_{series} - 20)$$

3.3.4. Determine the AC Resistance at T°C

$$R_{AC_T} = \frac{R_{AC_{25}} + (R_{AC_{75}} - R_{AC_{25}})}{(75 - 25)} \cdot (T_{series} - 25)$$

3.3.5. Calculate the Post-fault Rating

$$I_{PFR} = \sqrt{\frac{\frac{\Delta T}{t_{step}} \cdot mc}{\frac{R_{AC_T}}{1000}}}$$

Where t_{step} is an optional argument to the function (default 60 seconds)

Example

I_{PFR}
463.350
460.063
456.852
453.712
450.643
447.641
444.704
441.830
439.016
436.261

3.3.6. Determine the mean Post-fault Rating

Return the mean value from the post-fault rating series above

Example

$I_{PFRmean}$
449.407

3.4. Data Conditioning

The algorithm returns a raw value for the post-fault rating, which is likely to fluctuate highly with temperature, this would be an eccentric result, not useful for control room operations.

The PFR shall be given as a raw value and with and exponential moving average:

The Exponential moving average (EMA) is a parameter which balances the weightings at the beginning of the series by a decaying factor.

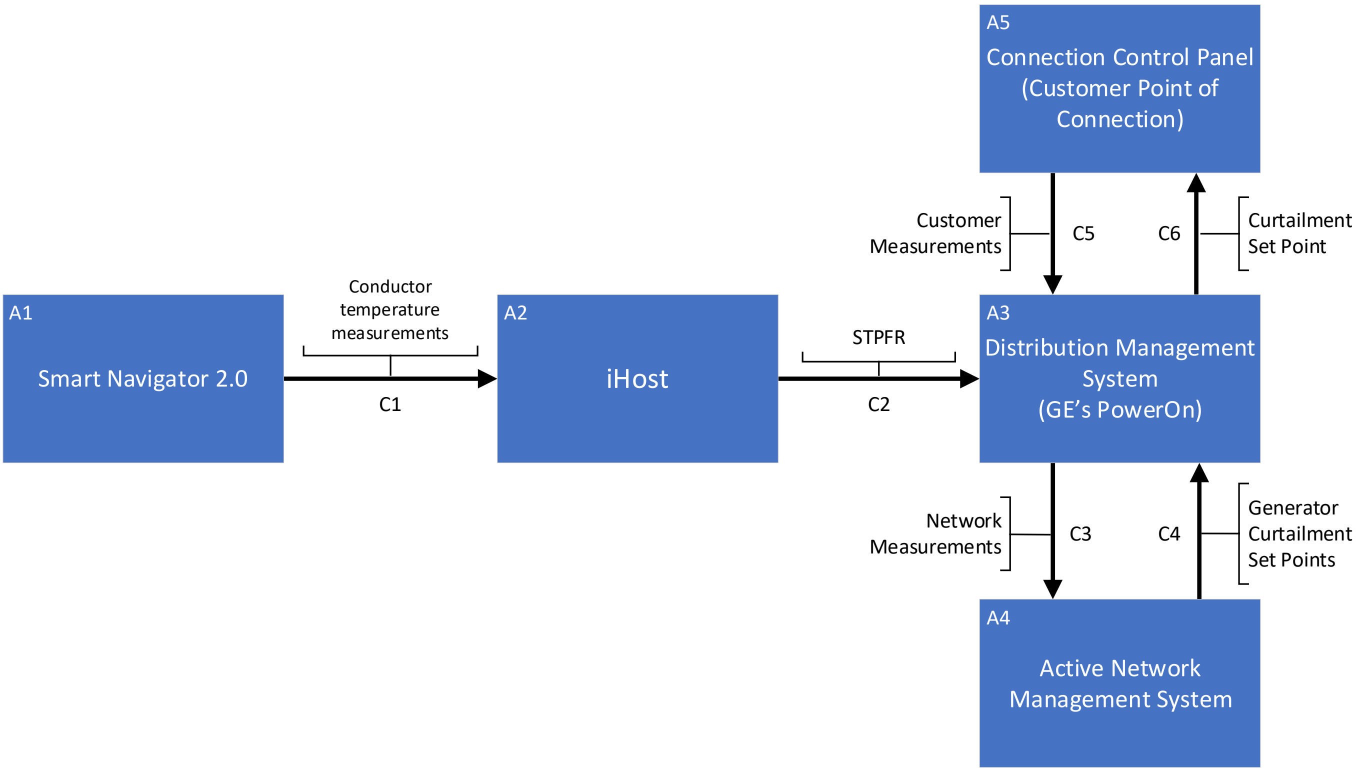
Each method shall consider a ‘span’ of the 10 most recent results.

4. Risk Assessment of STPFR Adoption

4.1. Introduction

This section completes a Failure Modes and Effects Analysis on the end to end system architecture in order to provide a comprehensive risk assessment. Additionally, mitigation recommendations are made for all potential failure points highlighted during the risk assessment.

4.2. STPFR Solution Architecture



4.3. Methodology

A Failure Modes and Effects Analysis (FMEA) has been conducted on the STPFR solution architecture in order to produce a comprehensive risk assessment of its implementation. This is a systematic method to evaluate each process and component in the system to identify how it may fail and what mitigations can be implemented to manage the failure modes.

The STPFR solution architecture shown above has identified 4 primary components, and 4 communications links.

4.4. Failure Modes and Effects Analysis

Ref. ID	Function	Potential Failure Mode	Potential Effects of Failure	Potential Causes of Failure	Recommended Actions	Responsible
A1	Smart Navigator 2.0	Loss of power	iHost unable to communicate with the Smart Navigator 2.0	Insufficient battery	Set up a battery warning before entering low power mode. Ensure the unit still communicates a fault but does not have to establish scheduled connections until fully recharged.	Nortech

		Unable to recharge	Unable to transmit OHL data	Low current in line	Ensure current on line is sufficient to charge. Ensure the installation is correct.	Nortech
		Faulty readings	Incorrect data transmission	Faulty instrumentation	Reconfigure the Smart Navigator. Ensure installation is correct.	Nortech
		Physical damage	Loss of data/ Poor quality data	Caused by the environment or a fault	Replace Smart Navigator Unit	Nortech
		Incorrectly configured	Incorrect Smart Navigator location/ incorrect OHL parameters	Software bug/ incorrectly commissioned	Reconfigure the Smart Navigator	Nortech
C1	Coms Links	Temporary loss of communications	Unable to monitor OHL	Network bandwidth limitations or network drops	Include a window of time for the unit to try and reconnect	WPD w/ support form Nortech
			iHost does not receive any data	Network drop/ software bug	Monitor the connection status	WPD w/ support form Nortech
C1	Coms Links	Permanent loss of communications	iHost does not receive any data	Comms network outage	Include a window of time for the unit to try and reconnect	WPD w/ support form Nortech
			Unstable monitoring system	Smart Navigator not connected to network	have an alternative method of communication, i.e.. a log or notification	WPD w/ support form Nortech
A2	iHost	Incorrect PFR rating	Provides a PFR that is too high or too low	Incorrect data supplied when set up with navigator	Ensure the correct Smart Navigator has been configured to the correct OHL	Nortech
		Failure to process data	Sends a fault to PowerOn	Software bug or connection loss	Poor quality signal sent to PowerOn. Verify connection through iHost.	Nortech
		Misconfigured/ software bug in the system	Cannot process data or connect with PowerOn	Software bug or misconfigured	Verify connection with iHost. Ensure coms links are operating correctly.	Nortech
		PFR rating is higher than static rating	Can damage the OHL if there are no other checks	Incorrect OHL parameters or data chosen	Have a redundancy check in the ANM system to default to the static seasonal rating	Nortech
C2	Coms Links	Temporary loss of communications	Unable to transmit STPFR	Network bandwidth limitations or network drops	Include a window of time for the unit to try and reconnect. If unable to, default to static rating.	WPD w/ support form Nortech
			PowerOn receives the incorrect STPFR	Fault in processing within iHost	Default to static rating	WPD w/ support form Nortech
C2	Coms Links	Permanent loss of communications	PowerOn does not receive any data	Coms network outage	Include a window of time for the unit to try and reconnect	WPD w/ support form Nortech
			PowerOn cannot communicate with iHost	Software bug	Have a stale data notification, default to static rating until coms are re-established.	WPD w/ support form Nortech
	PowerOn	Cannot connect with the ANM system	Cannot make changes to network	Coms link issues	Default to static rating until curtailment measures are received by the ANM system	WPD w/ support from GE
		Sends faulty data to the ANM system	Does not send the correct network data	Software bug or bad quality data	Ensure the ANM system has a final default safety rating in case of coms loss	WPD w/ support from GE

C3	Coms Links	Temporary loss of communications	Unable to monitor OHL	Network bandwidth limitations or network drops	Include a window of time for the unit to try and reconnect	WPD w/ support from GE
			ANM system does not receive any data	Coms loss of software bug	Have a safety redundancy in the ANM system for the static rating.	WPD w/ support from GE
C3	Coms Links	Permanent loss of communications	ANM system does not receive any data	Coms network outage	Include a window of time for the unit to try and reconnect	WPD w/ support from GE
			PowerOn cannot communicate with the ANM	Coms fault or network outage	Have an alternative method of communication.	WPD w/ support from GE
A4	ANM System	Gives incorrect curtailment instructions to PowerOn	Tells PowerOn to initiate curtailment that does not match the STPFR	Received poor quality data or has a software bug	Establish actions check to ensure the ANM agrees with iHost measures	ANM Provider
		Does not default to static rating if it does not receive a command	Forces a fault and system will run on higher PFR	Does not have static rating data stored in PSSE database	Ensure the default ratings are in the ANM system as well as the PSSE library	ANM Provider
		Received bad quality data	Cannot calculate the acceptable curtailment measures	Software bug/ coms link issues		ANM Provider
C4	Coms Links	Temporary loss of communications	Unable to monitor OHL	Network bandwidth limitations or network drops	Include a window of time for the unit to try and reconnect	WPD w/ support form ANM Provider
			ANM does not communicate with PowerOn	Software bug/ coms link issues	Establish alternative coms link or redundancy safety measures in PowerOn	WPD w/ support form ANM Provider
C4	Coms Links	Permanent loss of communications	ANM does not communicate with PowerOn	Coms network outage	Include a window of time for the unit to try and reconnect	WPD w/ support form Nortech
			ANM does not communicate with PowerOn	Software bug/ coms link issues	Have an alternative method of communication, i.e.. Not data, just a log or notification	WPD w/ support form Nortech
	Maintenance	PSSE database not correctly updated	Incorrect STPFR is calculated as it uses old OHL characteristics data	Database not updated when OHL is changed	Create procedure for any database update. Ensure iHost is informed of any changes to the OHL.	WPD w/ support form Nortech
		Smart Navigator 2.0 is moved to another OHL	The Smart Navigator 2.0 is not reconfigured to a new location in PowerOn and can display misleading data and incorrect ratings	Recommissioning process is not followed or completed	Produce recommissioning documentation so that the new location of the Smart Navigator 2.0 is verified both in iHost and PowerOn.	WPD w/ support form Nortech

4.5. Recommended Mitigations

The following mitigations are recommended and should be built into the system design.

1. A battery warning incorporated into iHost is established before the Smart Navigator 2.0 enters low power mode. When in low power mode, ensure the unit still communicates a fault but does not have to establish scheduled connections until fully recharged.
2. Include a window of time for the Smart Navigator 2.0 unit to try and reconnect. If a connection cannot be established due to a permanent loss of communications, an alternative communication method must be put in place.

3. Ensure the Smart Navigator 2.0 is correctly configured with iHost and the PowerOn system. An additional procedure can be implemented during the commissioning process to ensure the correct OHL is selected and the Smart Navigator 2.0 is associated to the correct location within PowerOn.
4. A failsafe rating library is available at all times to the ANM system (i.e., If iHost is unable to calculate a STPFR, an error message is sent through to the ANM system via PowerOn, but iHost itself does not contain the library of failsafe ratings).

5. Conclusion

This document has provided a functional specification for the short-term post-fault rating of overhead line conductors based on real-time reported conductor temperature measurements.

The post-fault rating function is most useful for overhead lines carrying large currents, where line current results in noticeable heating of the conductor above ambient temperature.

This technical specification has covered the following:

- A review of conductor characteristics used in the thermal model and an extended subset of the conductors used across the WPD network.
- A review of WPD's OHL policies to ensure conformity with current practices.
- Specifying the frequency of the STPFR calculation, the interval between routine conductor temperature monitoring from the OHL solution (review of input parameters of the algorithm to align with control room requirements) to feed into the technical specification.
- A risk assessment completed using the FMEA method to identify the following recommended mitigations:
    - A battery warning is established before the Smart Navigator 2.0 enters low power mode.
    - A window of time for the Smart Navigator 2.0 unit to try and reconnect before defaulting to an alternative method of communication.
    - Ensuring the Smart Navigator 2.0 is correctly configured with iHost and the PowerOn system. This will be accomplished using an additional verification step during the device commissioning.
    - A failsafe rating library is available at all times to the ANM system.

Following from this technical specification, a series of technical documents will be produced to:

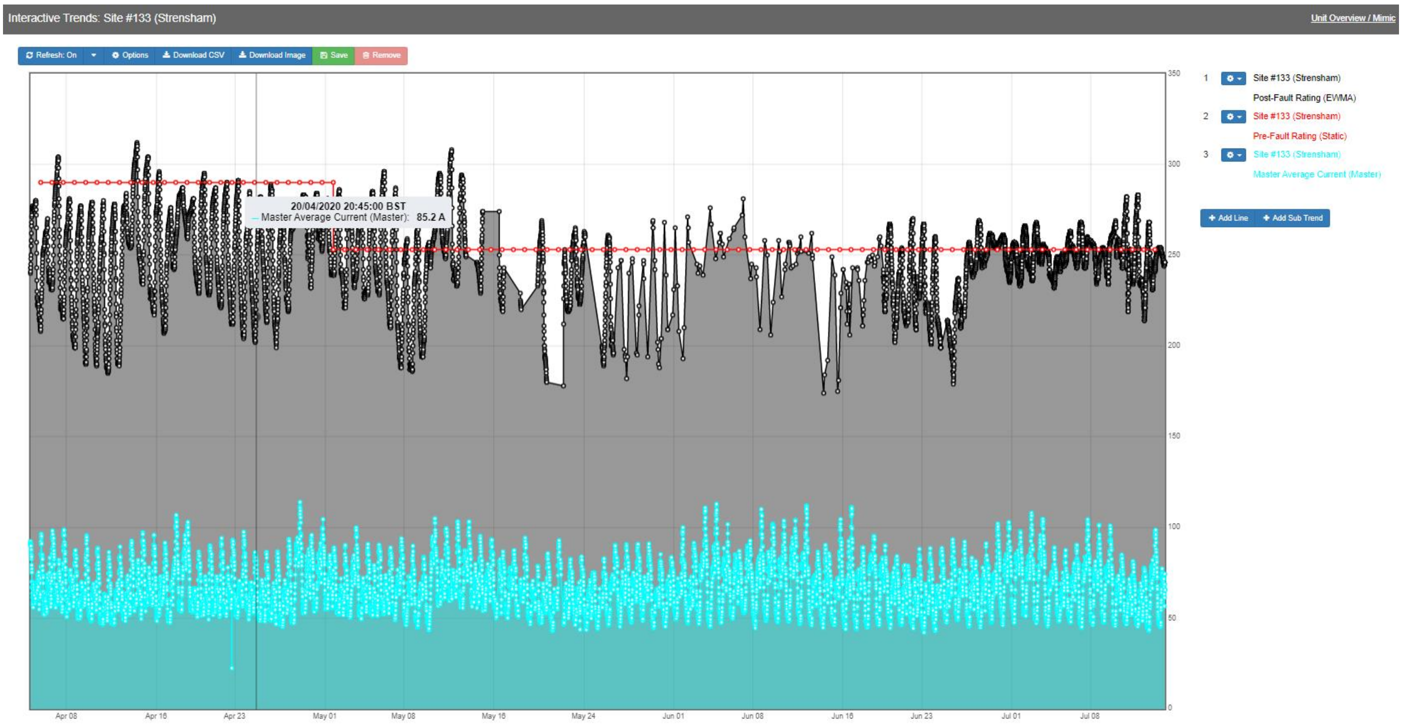
- Detail the network use cases and quantified benefits of the STPFR solution (WP3).
- Produce a specification for the ANM system including a proposed system architecture (WP4).
- Generate a finalised cost-benefit analysis of the STPFR solution and drafted policy recommendations (WP5).

Glossary

Abbreviation	Term
STPFR	Short-term Post-fault Rating
OHL	Overhead Line
PFR	Post-fault Rating
EMA	Exponential Moving Average

Appendices

Appendix 1 – Post-Fault Rating Chart (11kV example from iHost)



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