Technical recommendation for the purchase of Real Time Thermal Rating for transformers

1 Purpose

The purpose of this document is to set out and describe the technical requirements developed, that enabled the purchase of the Real-time Thermal Rating (RTTR) System to be applied to oil-immersed power transformers applied on the Northern Powergrid High Voltage power distribution networks that were trialled on the Customer-Led Network Revolution project.

2 Scope

This recommendation details the technical requirements for all equipment to be used in the calculation of oil-immersed power transformer real-time thermal ratings for transformer cooling types ONAN, ONAF, OFAF & ODAF.

The document applies to RTTR equipment on transformers between the following operating voltage levels:

- Extra High Voltage (≥ 22kV, < 132kV as specified in ENA ER 43-3) to High Voltage (>1000V, < 22kV as specified in ENA ER 43-3), known as Primary transformers
- High Voltage to Low Voltage (<1000V as specified in ENA ER 43-3), known as Distribution transformers

This recommendation includes the interfacing requirements with a remote server. A summary table of the supplier/product technical compliance is given in Appendix 1 & 2 for manufacturers to complete, detailing any variation.

Manufacturers are encouraged to offer more than one option if they have a number of possible solutions. The technical requirements detailed in the main body of this document are generic. Additional site specific data will be discussed with the potential supplier.

Contents

3 Technical Requirements

3.1 General

The component constituents of a primary transformer RTTR system are -

1. Measurement device(s):
    a. Temperature Sensors
    b. CTs
    c. VTs
    d. Tap position sensor
2. A local controller (including communication devices)
3. An RTTR calculation engine

Single weather stations and RTTR calculation engines should be capable of being used to support multiple sites.

All equipment intended for outdoor installation should be environmentally tested to IP55 and all internal equipment to IP52 in accordance with BSEN 60529. All equipment should be capable of operating under conditions of shock and vibration normally encountered in service on UK distribution networks. The dimensions of all equipment should be specified by the suppliers. All equipment with a real-time clock shall be capable of synchronisation with an Internet Engineering Task Force (IETF) standard Network Time Protocol version 4 (NTPv4) server.

3.1.1 Temperature Sensors

Temperature measurements are required to determine the winding hot-spot temperature. If the transformer has embedded temperature sensors, then this should be measured directly. For existing transformers where direct measurement is not possible, then the hot-spot temperature should be derived from the measured top-oil temperature, either using a recognised standard calculation (given in Table 2) or a load-related heating element in the oil pocket.

If it is proposed to use readings from existing analogue Winding Temperature Indicators then evidence of the accuracy and feasibility of this process must be supplied.

Options for application to Distribution transformers without oil pockets would be attractive but must provide evidence of their accuracy.

3.1.2 Weather Measurement Devices

Ambient temperature sensors should be installed at least 2 meters away from the transformer and protected from draughts, direct sunlight and other heat sources.

Where wind cooling or solar heating of transformers significantly impacts on the transformer rating, it may be advantageous to measure and model these effects if suitable models are available.

3.1.3 Voltage and Current Measurement Devices

It is expected that the measurement of the transformer loading (voltage and current) will be made on the secondary side of the transformer, using the existing CTs and VTs provided for the protection and tap control systems. It is not acceptable to disconnect these CT circuits during installation so appropriate secondary (“wedding ring”) transducers will be required to fit around the existing CT wiring. VT connections must be fully isolated from ground (VT star point may not be at earth potential) and impose minimal loading upon the VT secondary winding.

For distribution transformers feeding the LV Distribution network voltage should be directly measured from the LV bus-bars, and the equipment must be designed for safe connection to these. Load current will also need to be directly measured using suitable split-core Rogowski Coils or CTs around the LV bus-bars.

3.1.4 Tap Position Sensor

Where transformers are fitted with a tap changer and automatic voltage control system, the tap position is required in order to obtain correct RTTR outputs. Where automatic voltage control is provided by a modern digital relay, the tap position shall be obtained from the relay.

If it is proposed to obtain tap position from existing analogue tap control systems then evidence of the accuracy and feasibility of this process must be supplied.

For transformers with fixed taps, tap position sensing is not required and the tap position used should be set as a static parameter (Table 4).

3.2 Local Controller

The local controller is responsible for collecting the data from the various sensors and acting as single point of communication to the RTTR Calculation Engine.

Table 1: Device technical specifications

Parameter	Local Controller
Ingress protection	External: IP55, Internal: IP52
Operating temperature	-20°C to 40°C
Maintenance & Lifetime	>10 years
Maximum weight	25kg
Minimum sampling rate	10 minute capability(user configurable)
UV stability	Stable in accordance with BS 2782-5: method 22A
Unit impact resistance	2 Joules
Humidity levels	0 – 100%
Mounting location	Wall mounted

3.3 RTTR Calculation Engine

The RTTR calculation engine is the software responsible for calculating the RTTR using both time-series and static parameters as inputs. The model shall be based on one of the standard thermal models shown in Table 2. The RTTR is defined as the maximum load that the transformer can sustain, for a defined time period, without the winding hot-spot temperature reaching its limit.

Table 2: Thermal Models

Thermal Models
IEC 60076 Part 7
IEEE C57 91-1995

Where a potential supplier has previous documented experience demonstrating that their product uses a variation from these standards, but can achieve improved accuracy, then this will be considered. Any RTTR models using a different methodology, for example a model accredited by an alternative reputable standards body, may be acceptable if the supplier provides clear evidence of its accuracy.

Parameters that should be measured unless otherwise specified by the Network Operator are listed in Table 3. The static parameters required for modelling purposes are listed in

Table 4. If manufacturers do not require any of the parameter(s) in Table 4 to calculate RTTR, or a value is assumed, this should be specified.

Table 3: Time-series parameters

Measured Parameters	Accuracy	Precision	Range
Top-oil temperature	±1°C	0.5°C	-20°C to 100°C
Current	±1%	1A (load current)	Secondary CT on 1A or 5A CT wiring
Voltage	2% nominal	0.5% nominal	63.5 - 250V (VT Output)
Tap position	Exact	Exact	≥39 tap positions

Table 4: Static Parameters

Static Parameters
Top-oil temperature rise at rated load, $\Delta\theta_{or}$
Load loss ratio, R
Oil exponent, x
Hot-spot factor, H
Winding to oil gradient at rated load, g_r
Winding exponent, y
Thermal model constants, k_{11}, k_{21}, k_{22}
Oil time constant, τ_0
Winding time constant, τ_W
Maximum tap position tap_{max}

Static Parameters
Minimum tap position tap_{min}
Tap loss ratio gradient (lower), m_1
Tap loss ratio gradient (higher), m_2
Default tap position, r
Maximum load factor, K_{max}
Fixed tap position (on transformers not fitted with tap changer)

3.4 Weather Measurement Device Outputs

The weather measurement device should provide the data listed in Table 5.

Table 5: Weather measurement device output (location dependent)

Measurement	Accuracy	Precision	Range
Ambient temperature	±1°C	0.5°C	-20°C to 40°C

3.5 RTTR Calculation Engine Outputs

Table 6 shows the outputs required from the RTTR Calculation Engine. Output parameters should be time-stamped with an accuracy of ±5 seconds and a precision of ±1 second. All time parameters are to be accepted and output in UTC. An option to convert to configurable local time zones for user interaction may be provided. Where additional outputs are available these should be specified by manufacturers. RTTR settings should be configurable, including:-

- Changes to the static parameters;
- Changes to the maximum permitted hot-spot temperature;

Table 6: RTTR model outputs

Output
Maximum Capacity for 1, 3, 6, 12 hours without hot-spot temperature limit being reached
Time existing load can be carried under present conditions
Health Alerts (for the RTTR system)

3.6 RTTR Model Features

The development of RTTR models for transformers is developing area, and a number of projects are ongoing to develop more advanced and flexible models.

Providing all the relevant static inputs (Table 4) to the model for a specific transformer will be challenging, especially if it has been in service for some time. It would advantageous to utilise a self-learning model which would adapt these parameters to the transformer in a closed-loop manner. This would deal with missing information, changes in transformer parameters with age, and also address concerns about the differences between transformers of the same name-plate capacity from different manufacturers, and the amount of

engineered in extra capacity. A system using such a model must be automatically protected against learning errors caused by sensor failure.

The question of accurate ratings for indoor transformers (where air cooling is restricted by the building) will also be aided by a self-learning model, although one which is capable of using a real-time building air temperature input as well as outdoor ambient temperature may deliver many of the same benefits. Both these go beyond the processes described in the standard thermal models (Table 2).

3.7 Communication between System Components

All systems should be suitable to communicate with industry standard SCADA protocols; this should be via direct communication or by using an intermediate device. The preferred protocols are likely to be DNP3 or IEC 61850. In all cases the communications equipment must be compliant with the EMC requirements given in Appendix 7. The manufacturer will be required to agree the communications protocol and format of data with the purchasing Network Operator.

For communications between Measurement Devices and the Local Controller, a communications link suitable for operation over standard pairs in existing pilot cables will be preferred. The number of pairs required between each item of equipment must be specified.

3.8 Safety

Live line working is permitted on UK Distribution Networks, typically up to 33kV although limits do vary. This is subject to suitable working practices being developed and the appropriate health and safety policies. Systems which can be installed without the need for outages will be preferred. Where applicable, potential suppliers should comply with their statutory obligations under the Construction (Design and Management) Regulations 2007, in particular, to avoid foreseeable risks to those involved in the installation and further use of the equipment. A list of appropriate BS, ENA standards and guidelines are given at the end of this document; these should be adhered and conformed to. Manufacturers should provide example procedures, method statements and risk assessments to the Network Operator to facilitate the assessment of safe installation procedures, for both live and dead installations.

4 References

The products described within this recommendation should comply with the latest versions of the relevant International Standards, British Standard Specifications and all relevant Energy Network Association Technical Specifications (ENATS) current at the time of supply.

4.1 External Documentation

Reference	Title
BS 2782-5	Methods of testing plastics — Optical and colour properties, weathering — Determination of changes in colour and variations in properties after exposure to daylight under glass, natural weathering or laboratory light sources
BS EN 60801-2 : 1993	Electromagnetic compatibility for industrial-process measurement and control equipment. Electrostatic discharge requirements
BS EN 61000	Electromagnetic compatibility
BS EN 61000-4-2 :2009	Electrostatic Discharge Immunity test
BS EN 61000-4-3 :2006 +A2:2010	Testing and measurement techniques. Radiated, radio-frequency, electromagnetic field immunity test
BS EN 61000-4-4:2004-07	Testing and measurement techniques - Electrical fast transient/burst immunity test
BS EN 61000-6-2 :2005	Generic standards - Immunity standards for industrial environments.
BS EN 61000-6-3:2007 +A1:2011	Generic standards - Emission standards for residential, commercial and light-industrial environments
BSEN60529	Degrees of protection provided by Enclosures (IP Code)
ENA ER P15, 1971	Transformer Loading Guide: A Guide to the Loading of Double Wound Transformers having Nominal ratings of 120MVA and below, supplying systems at 66kV and below from Supergrid and 132kV systems.
IEC 60076 Part 7	Loading guide for oil-immersed power transformers
IEEE C57.91-2011	Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators
IETF RFC 5905	Network Time Protocol Version 4: Protocol and Algorithms Specification
IETF RFC 5906	Network Time Protocol Version 4: Autokey Specification
IETF RFC 5907	Definitions of Managed Objects for Network Time Protocol Version 4

The supplier should provide with the tender full technical details of the equipment offered and should indicate any divergence from these standards or specifications.

5 Definitions

Term	Definition
RTTR	Real-time Thermal Rating
NTP	Network Time Protocol (see IETF RFC 5905)
IP	Ingress Protection
CT	Current Transformer
VT	Voltage Transformer
WTI	Winding Temperature Indicator
BS	British Standard
DNO	Distribution Network Operator
EMC	Electromagnetic Compatibility
ENA	Energy Networks Association
GPRS	General Packet Radio Services (GPRS) is a packet-based wireless communication service that provides data rates from 56 up to 114 Kbps and continuous connection to the Internet for mobile phone and computer users. GPRS is based on Global System for Mobile (GSM) communication system.
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force, a standards organisation for the Internet
NA	Not Applicable
RFC	Request For Comment, a standardisation document issued by the IETF.
UTC	Universal Coordinated Time, the international time standard with no seasonal changes to which all other time zones are referenced (aligned to GMT in UK winter).
UV	Ultraviolet
Primary Transformer	A transformer supplied from the Primary Distribution network at EHV (typically 33kV or 132kV), with its output onto the Secondary Distribution network at HV (typically 11kV)
Distribution Transformer	A transformer supplied from the Secondary Distribution network at HV (typically 11kV), with its output onto the LV Distribution network (400V)

Appendix 1 – Schedule of Suppliers Technical Data

The following Technical schedules must be completed by suppliers

Weather measurement device technical specification (Table 1)

Parameter	Conformity (Yes / No – comments)
Power supply	
Ingress protection	
Operating temperature	
Maintenance	
Lifetime	
Maximum weight	
Sampling rate	
UV stability	
Unit impact resistance	
Humidity levels	
Mounting location	

Local controller technical specification (Table 1)

Parameter	Conformity (Yes / No – comments)
Power supply	
Ingress protection	
Operating temperature	
Maintenance	
Lifetime	
Maximum weight	
Sampling rate	
UV stability	
Unit impact resistance	
Humidity levels	
Mounting location	

Compliance with thermal models (Table 2)

Thermal Models	Conformity (Y / N – comments)
IEC 60076 Part 7	
IEEE C57.91-2011	

Appendix 2 – Self Certification Conformance Declaration

Supplier/Product Technical Compliance Grid (to be completed by the supplier for each variant offered).

The measurement devices, local controller and calculation engine shall comply with the latest issues of the IEC's and British Standards quoted within this specification.

Key elements from the above standards and this specification have been quoted to amplify and/or clarify the requirements of those Standards. This check sheet identifies the particular clauses of the aforementioned Standards relevant to Primary Transformer RTTR systems.

The manufacturer shall declare conformance or otherwise, clause by clause, using the following levels of conformance declaration codes for each conductor.

Conformance declaration codes:
N/A = Clause is not applicable/ appropriate to the product
Cs1 = The product conforms fully with the requirements of this clause
Cs2 = The product conforms partially with the requirements of this clause
Cs3 = The product does not conform to the requirements of this clause
Cs4 = The product does not currently conform to the requirements of this clause, but the manufacturer proposes to modify and test the product in order to conform.

Instructions for completion

- When Cs1 code is entered no remark is necessary
- When any other code is entered the reason for non-conformance shall be entered
- Prefix each remark with the relevant 'BS EN' or 'ENATS' as appropriate

Note:
Separate Self Certification Conformance Declaration sheets shall be completed for each product being offered.

Manufacturer:
Product Reference:
Name: **Signature:** **Date:**

Specific requirements within this specification			
Clause/Sub-clause	Requirements	Conformance Code	Remarks
Table 1	Compliance with device technical specifications		
Table 2	Compliance with one or more specified thermal model(s)		
Table 3	Compliance with fixed parameters		
Table 4	Compliance with site dependent parameters		
Table 5	Compliance with RTTR model outputs		
Table 6	Compliance with wind measurement device outputs		

Electromagnetic Compatibility			
Clause/Sub-clause	Requirements	Conformance Code	Remarks
BS EN 61000-6-3:2007	Emission standards for residential, commercial and light industrial environments.		
BS EN 61000-6-2:2005	Immunity Standards – Immunity for industrial environments		
BS EN 60801-2:1993	EMC for industrial-process measurement and control equipment – Electrostatic discharge requirements **Min values** Air – 4kV Contacts – 8kV		
BS EN 61000-4-3:2002	EMC – Radiated, radio- frequency, electromagnetic field immunity test **Min Values** 27Mhz – 1Ghz @ 10V/m 80Mhz – 1Ghz @ 10V/m		
IEC 61000-4-4:2004	EMC – Electrical fast transient/burst immunity test **Min values** +/- 1kV		
BS EN 61000-4-6:2007	EMC - Immunity to conducted disturbances induced by radio frequency fields **Min Values** 150khz – 80Mhz @ 10V/m		

Appendix 3 – Addendum to Supplier Requirements

Please indicate Packaging/delivery information

Details of how this product will be packaged and delivered shall be provided.

Please indicate dimensions of RTTR system components

Details of the individual RTTR system component dimensions shall be provided.

Please indicate options for location of the calculation engine

Details of how the calculation engine software can be hosted.

Project specific requirements

Any project specific requirements will be provided by the purchasing Network Operator for inclusion in this appendix.

Appendix 4 - Pre-commission testing, Routine Inspection and Maintenance requirements

Suppliers shall provide details of any recommended pre-commission testing or installation requirements. Additionally suppliers shall also provide information regarding any periodic inspection or maintenance requirements to be undertaken during the lifetime of their product.

Appendix 5 - Technical Information Check List

The following information shall be provided by the supplier for technical review by Northern Powergrid UK. Additional information shall be provided if requested.

Requirement	**Provided (Y/N)**
Appendix 1 – Completed technical schedules	
Appendix 2 – Completed self-certification conformance declaration	
Appendix 4 – Inspection and testing recommendations	
Appendix 7 – Electromagnetic compatibility	
Type test evidence	
Routine test plan (example)	
Packaging/delivery information	

Appendix 6 – Schedule of Components

Item	Description	Price
1	Weather Measurement Devices	
2	Transformer Measurement Devices	
3	Local Controllers	
4	RTTR calculation engine	

Appendix 7 – Electromagnetic Compatibility

Electromagnetic Compatibility Tests for equipment

All equipment shall be compatible with the following generic EMC standards:

- BS EN 61000-6-3: 2007 - Generic Emissions standard
- BS EN 61000-6-2: 2005 - Generic Immunity standard
- BS EN 61000-4-2: 1995 - Electrostatic discharge immunity Test (Requirement Air 8kV, Contact 4kV)
- BS EN 61000-4-3: 2006 Radiated radio Frequency, Electromagnetic Field Immunity. (Requirement 80MHz-1GHz @ 10V/m)
- BS EN 61000-4-6: 2007 Immunity to conducted disturbances induced by radio frequency fields. (Requirement 150kHz - 80MHz @ 10V/m)
- BS EN 61000-4-4: 2004 Electrical Fast Transient/Bursts Immunity (Requirements +/- 1kV).