Belgian experience with real time thermal rating system in combination with distributed temperature sensing techniques

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ABSTRACT

The first real time thermal rating (RTTR) monitoring system of Elia is installed on a 33 km long cable link of 150 kV between Koksijde and Slijkens (type EAXeCeW 87/150 kV 1x2000/211). This link is highly loaded due to the connection of offshore wind farms (e.g. Thornton Bank). The load will even increase with the future connection of other planned wind farms (e.g. Norther). The measurement data of the distributed temperature system (DTS) is transferred to a RTTR system. The EMS systems sends further input to the RTTR. The RTTR sends the results of the calculations, the real time load capability of the cable link, to the EMS system. With the technique of RTTR, Elia has the opportunity to follow up the load in real time and to have an idea of the maximum instant load and the overload capabilities of the cable system. This paper explains the experience of Elia with the installation of the RTTR system and the first insights about the overload capability of the 150 kV link.

KEYWORDS

RTTR, DTS, overload capability, DRS, dynamic rating, temperature measurement

INTRODUCTION

In the late 90's, the Belgian TSO Elia decided to integrate optical fibres in HV cable systems of 150 kV for temperature monitoring. Up till now these fibres were used for ad-hoc temperature measurements on the cable circuits by means of a mobile DTS system. The goal of this technique was to locate hot spots in the circuit and to verify the ampacity calculations made during the engineering and construction phase of the circuit. There was no direct need for permanent temperature measurement due to the relative low load of these cable systems. Meanwhile the situation has changed and several cables are already or will be highly loaded in the near future due to decentralized and renewable energy (RES) production, especially wind energy production. The load situation in the grid is changing rapidly from a unidirectional to a bidirectional network. At this moment there is a need from the grid operations side to be able to operate certain cable systems on a dynamic way by using permanent RTTR systems.

Description of the 150 kV cable

The 150 kV cable link between Koksijde and Slijkens is 33 km long. The cable type EAXeCeWB 87/150 kV 1x2000/211 is composed of an aluminium conductor, XLPE insulation, Cu wire screen combined with an aluminium foil (see figure 1) and was installed in 2006 in a controlled backfill, trefoil configuration with direct cross-bonded of the screens.

One phase of the cable link is equipped with integrated optical fibres (FO). These fibres are located under the outer sheath of the cable. Two different types of fibres are used: multimode (MM) fibres and single mode (SM) fibres. The MM fibres are preferentially used for temperature measurements with MM DTS systems, due to the higher accuracy and the lower spatial resolution. The SM fibres are used for longer ranges, were the MM DTS systems are not capable to measure the complete cable length.

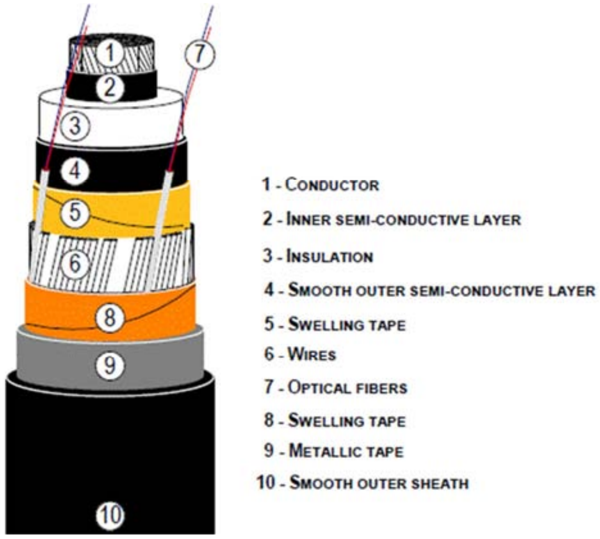

Fig. 1: overview of 150 kV cable

The fibres are installed in a stainless steel tube, placed under the metallic radial water barrier of the cable.

Increasing RES at coastal region

The growth of decentral production at the coastal region is expanding rapidly.

At the coastal region different offshore wind parks are located. The C-power wind park, with a capacity of 325 MW, is directly connected at the substation of Slijkens. Other wind parks, like Northwind (216 MW) and Belwind (165 MW), have a total capacity of 380 MW in april 2015. Other wind parks are planned with an expected total energy production of more than 2000 MW. Beside wind energy also solar power increases the power production with an expected raise of ~100 MW. See figure 2 of a complete overview.

The peak power plant at Herdersbrug (300 MW) helps to balance the production and demand in Belgium. These RES and peak demand production are all connected to the the 150 kV grid in the coastal region. The underground cable link between the 150 kV substations of Koksijde and Slijkens is a major connection in the region.

As a consequence, in order to transport the additional wind power inland, a fluctuation of the cable load with peaks exceeding the maximum transport capacity during short periods of time are observed.

The RTTR system should allow a more optimal use of this cable connection and the 150kV grid in general. It increases the possible connections of renewable generations.

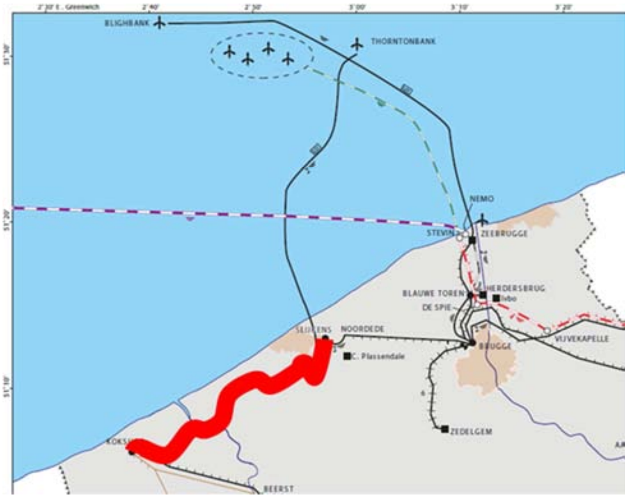

Fig. 2: schema of the coastal region and indication of the 150 kV between Koksijde and Slijkens

Study of maximum charge of cable system

Elia carried out theoretical studies in order to define the maximum load of the 150 kV cable system. In this study all hot-spots were defined and the maximum load for every hot-spot was calculated accordingly.

In the standard cable trench (see fig. 3) the calculated load is 1372 A (356 MVA) for a burial depth ≤ 2,5 m and 1412 A (366 MVA) for a burial depth between 2,5 m and 3,0 m.

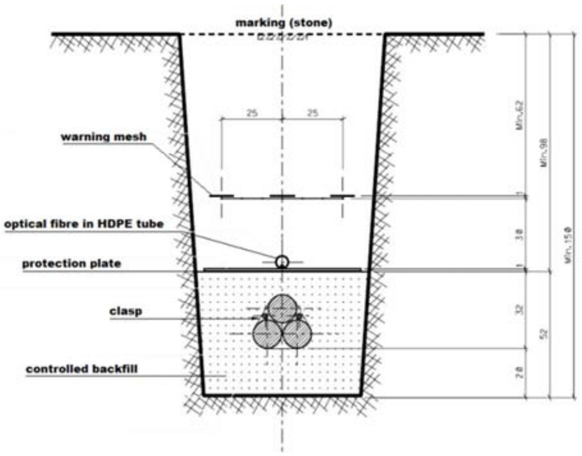

Fig. 3: normal trench of cable

Along the cable route more than 30 horizontal directional drillings (HDD's) were installed. The maximum load of each HDD was calculated at the lowest point of the HDD with a thermal model of the actual laying configuration of the cable. The tubes of every HDD are filled with bentonite mixture (thermal resistivity ρ ≤ 1 K.m / W). For the calculation of the ampacity, soil samples were taken at both sides of the HDD's to quantify the thermal resistivity of the surrounding soil.

The most critical HDD's (hot-spots) are listed in table 1:

HDD	Depth (m)	$\rho_{soil, wet}$ (K.m / W)	Max. load (A)
HDD CS191	3,0	0,96	1329
HDD CS172	6,8	1,00	1330
HDD CS174	4,05	0,87	1336
HDD CS121	5,0	0,80	1351
HDD CS180	7,68	0,71	1386

Table 1: most important calculated hot-spots

At road crossings, the cables are installed in ducts. To avoid hot spots at these locations all ducts were filled with the same bentonite-mixture.

Near the Slijkens substation, the link crosses the Oostende-Bruges water channel and the cable passes in an existing technical tunnel under this channel. This concrete tunnel has 25 m deep shafts at both sides, a horizontal length of 120 m, and a diameter of 2.5 m [1]. The transport capacity was calculated, taking into account an ambient temperature of 35°C, and fixed to 1690 A.

Based on all calculations the maximum transport capacity of the cable link was set to 340 MVA.

Technical requirements of RTTR system

The Real Time Thermal Rating systems should allow cable charging at his thermal limits on a dynamic and secure way.

Figure 4 shows the schematic diagram of the RTTR system.

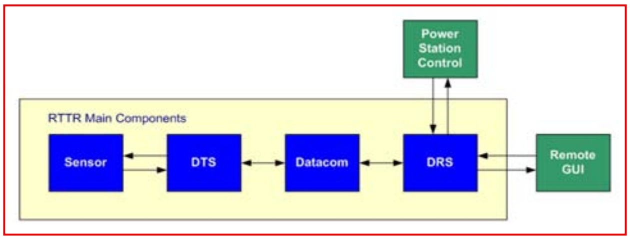

Fig. 4: schematic overview of different RTTR components

The DTS measures through an embedded optical fibre the temperature along the cable route. The temperature profile is send over the Elia data network to the server room. Here the RTTR server is installed which calculates the corresponding conductor temperature, taken into account the actual current of the cable. This information comes from the EMS. A web based interface shows the (over)load and temperature information.

The RTTR system uses thermal models (equivalent circuits) for the monitored cable system based on the IEC 60287 [4] and IEC 60853 [5] standards. The complete cable link is divided in 197 thermal zones, each with their equivalent thermal model, in order to calculate the conductor temperature. In the thermal model the real laying conditions of the corresponding zone are integrated.

The DTS system measures continuously the temperature along the cable system. Due to the long cable length (33 km), the RTTR system uses the real current distribution over the cable length, taking into account the capacitive current (see figure 5).

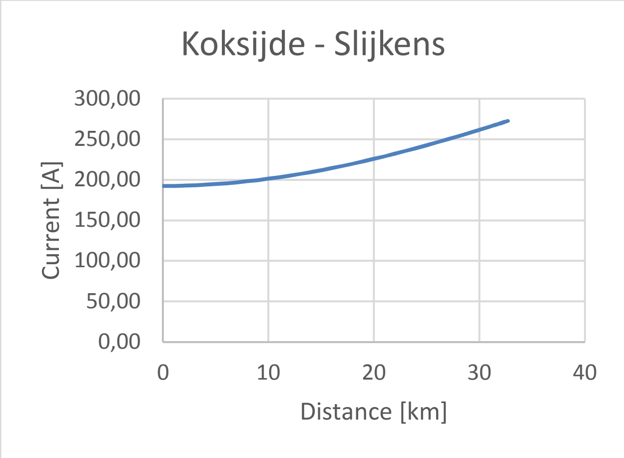

Fig. 5: calculated current - power 50 MW at Koksijde

The calculations for each thermal zone use the maximum temperature measured in this zone and the corresponding (calculated) current for this zone.

The RTTR system calculates the corresponding conductor temperature for each thermal zone and determines the maximum permanent current for each zone. The RTTR provide an overview of the 5 most critical zones of the cable system and a history of the most critical hot spots since the commissioning.

As requested by the grid operators, the RTTR system calculates every 15 minutes the maximum permanent load, the maximum cyclic load of the cable link and the overload capability of the cable system during 4 and 36 hours. The 4 hours forecast is used for emergency situations, while the 36 hours is used as a day ahead forecast to determine energy trading capabilities.

Communication with EMS system

The actual load information and overload possibilities are communicated to the SCADA system (EMS) using the IEC 60870-6 / TASE2 (ICCP) protocol.

Following parameters are transferred:

- General status of the system
- Permanent load of the cable
- Overload conditions on 4 hour and 36 hours
- Calculated temperature of most critical hot-spot

The general status (OK / NOK) is the trigger to use the information from the RTTR system. Only when the accuracy of the system is reliable and all components work properly - DTS, RTTR, communication and installed software – the grid operator can use the information from the RTTR.

The communication between RTTR and EMS (SCADA) is established using a software protocol convertor.

Experience feedback

The stability of the communication path from the RTTR towards the SCADA was very challenging. After installation unforeseen problems occurred which disturbed the communication: bugs in software modules, wrong calculation of average values received from the EMS,...

For a smooth implementation of the RTTR system in the data-communication network, the TSO several parameters must be identified before the installation takes place:

- The frequency of data transfer between different components (RTTR to EMS and vice versa, DTS to RTTR,...);
- Dataflow between different components with communication protocols, used ports, bandwidth,...
- Description how the data integrity is assured;
- Total data volume.

In order to verify the stability of the communication with the SCADA system it is recommended to test this communication during the FAT and run the entire RTTR system after installation during a few weeks before starting the SAT.

Power back-up

A UPS is installed to guaranty the functionality of the RTTR system when voltage dips and short power interruptions occur. The UPS allows a safe shutdown of the DTS when the power interruption is longer than 5 minutes (programmable).

The complete RTTR system is configured in such a way that after a power interruption the complete system (RTTR, DTS, servers, etc.) restarts automatically when the power is coming up again. Once the requested accuracy is reached again, a message is sent to the EMS system to confirm that the system is back operational and reliable.

Experience feedback

Since the RTTR system is installed on a cable system with an expected lifetime of 50 years, the lifetime of the RTTR, DTS, UPS should be as long as possible. Currently batteries with a certified lifetime of 10 year are available.

Temperature measurements

The DTS measurement system is located at the substation of Slijkens. The DTS measures the Brillouin frequency to determine the temperature along the cable route.

Calibration of the DTS

The cable Brillouin response shows that the cable is made of 27 clearly identifiable different sections. Apart from minor variation due to the dispersion in the fibre manufacturing process, we can clearly see 3 different Brillouin frequencies (different types from same manufacturers) as can be seen in Figure 6.

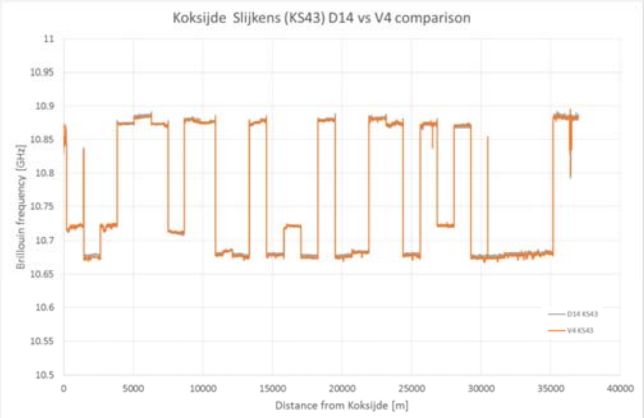

Fig. 6: Brillouin response showing the different optical fibre sections

During the calibration the offset of the 3 different Brillouin frequencies are aligned in order to have one continuous thermal profile. For the relationship between frequency and temperature a fibre dependent calibration coefficient is used for the slope (namely 1.05 MHz / °C). Figure 7 gives an example of diagram with the measured frequency vs. temperature.

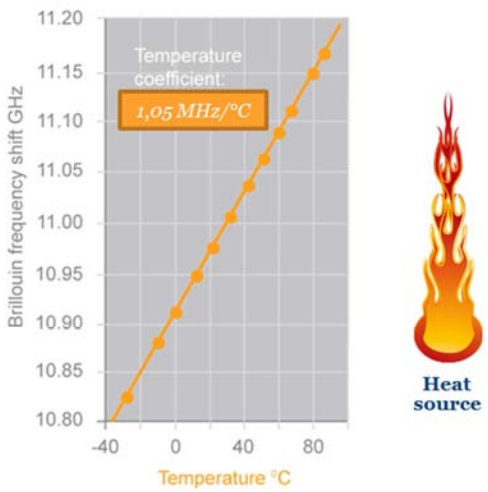

Fig. 7: measured frequency vs. temperature

To measure the absolute temperature with Brillouin the value of the offset has to be fixed. At the substation of Koksijde, the opposite location where the DTS is installed, a patchcord with well know characteristics and slope is connected to the optical fibre and heated in a water bath to define the absolute temperature of the offset.

Since the Brillouin frequency is used: both temperature and strain are measured. Since the strain measurement is unwanted it is important to detect and eliminate strain problems.

Accuracy of the temperature measurements

The requested accuracy for the DTS system is ± 2°C at a fibre length of 40 km with a spatial resolution of 2 m and a response time of 15 min.

The overall accuracy of the complete RTTR system is ± 4°C.

Experience feedback

In order to calibrate the DTS with Brillouin frequency it is necessary to have an overview of all optical splices. In particular in the proximity of the substation many variations in the frequency were noted since the optical fibre leaves the power cable and enters the relay room. The optical fibre is spliced to an external fibre cable with other characteristics.

The absolute values of all measurements are dependent on the accuracy of the calibration. The calibration should be performed using a calibrated thermometer, stable temperature environment and with an optical fibre of which the characteristics are well known.

During the SAT two strain problems occurred resulting respectively in an illogical cold spot (see Fig. 8) and hot spot.

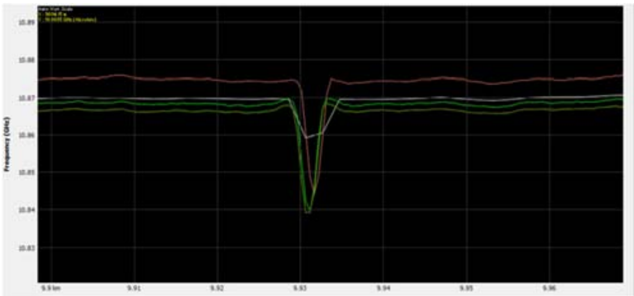

Fig. 8: cold spot at 9,93 km fibre length

In order to evaluate the strain problem the result of the measurement was compared with the measurement of a mobile DTS with a range of 15 km using Raman technology. This type of DTS doesn't measure strain. After the confirmation of the presence, the offset at the cold spot was corrected.

Load limitations of other equipment

The theoretical permanent load of the cable is 1307 A at 150 kV (340 MVA). If order to use the dynamic capabilities of the RTTR system the other components in the link between both substations must be verified with relation to their maximum currents (permanent load and overload information is applicable).

Substation of Slijkens

At the substation of Slijkens the cable system is directly connected to a GIS system. Table 2 summarizes the load limitations for the complete GIS installation:

Component GIS Slijkens	T_{amb}	I_{nom}
Switchgear Slijkens	0°C	4000A
	30°C	2160 A
	40°C	2000 A

Table 2: overview load limitations GIS

Substation of Koksijde

In the substation of Koksijde the cable is connected to an AIS bay, equipped with current transformers, voltage transformers, a circuit breaker and flexible connections between all components (see figure 9).

Fig. 9: AIS substation in Koksijde

Table 3 & 4 below give a summary of the load limitations for the flexible AMS line connection and of the main AIS components.

Component AIS Koksijde	T_{amb}	$I_{overload}$
Line connection 1x 707 AMS-2Z	0°C	1663 A
	30°C	1330 A

Table 3: overview load limitations flex connections

For the flexible connections a AAAC 1x 707mm² conductor is used. The overload current, calculated at a conductor temperature of 90°C, is verified with a thermographic study in order to control the different electrical contacts.

Component AIS Koksijde	T_{amb}	I_{nom}
Circuit breaker Koksijde	0-30°C	> 5000 A
	40°C	3150 A
Current transformator (TI)	0-10°C	2175 A
	>10°C	1800 A
Disconnector of the rails	< 20°C	2750 A
	30°C- 40°C	2500A

Table 4: overview load limitations of bay components

The information about the load limitations of the other equipment are integrated in the RTTR system by the use of a 'limiting maximum current value'. The (over)load information and simulations on the RTTR GUI will never exceed the limiting value.

Experience feedback

As a result of this study the flexible connections 1x707 mm² AAAC are detected as the next critical component. On a short time period Elia will replace these flexible connections by 2x707 mm² AAAC in order to increase the overload capabilities of the entire cable link.

GUI of RTTR system

The RTTR GUI main page displays all information from and towards the SCADA system and the information about the hot spot of the cable route, maximum actual load and highest calculated conductor temperature.

On another page the detailed temperature and ampacity information is shown (see figu-re 10) together with the list of 5 most critical hotspots.

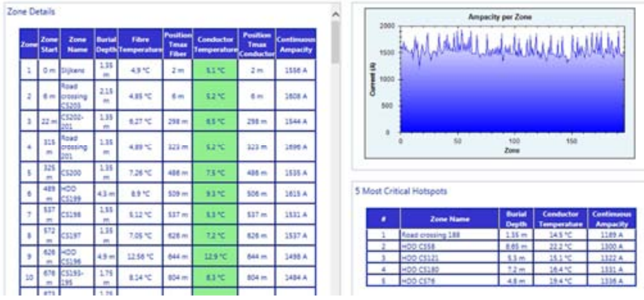

Fig. 10: temperature and ampacity per zone

A separate section allows simulation of overload conditions for the cable, based on the maximum calculated temperature, with 2 out of 3 variable parameters: temperature, time and current. The grid operators use this section to simulate very specific overload patterns.

The RTTR GUI gives an overview of the monitored cable system, with indication of the status of each zone: normal, warning, alarm.

The warning level for the calculated temperature is set to 75°C and the alarm level to 86°C: 90°C minus the accuracy of the complete RTTR system (4°C). When a warning or alarm is generated, automatically an email is sent with more detailed information (zone, temperature parameters, position,...).

For every thermal zone, detailed information about the actual status, visualization of timestamp of the last measurement, calculated current, measured DTS temperature and calculated conductor temperature is shown on request (see figure 11).

Fig. 11: zone information

Experience feedback

Before commissioning, the start- and the endpoint of every thermal zone is defined based on the as-built construction drawings of the cable route. The transition from one zone to another is fixed where the cable laying conditions change: different type of cable trench, different laying depths, cable placed in tubes, HDD,... .

The real 'thermal' situation can differ from the drawing and therefore the start- and the endpoint of every zone needs to be evaluated and re-adjusted. Because the laying conditions are the same, the temperature in a thermal zone should therefore be more or less constant.

First study of the measured hot spots

When theoretical hot spots (see 'study of maximum charge of cable system') are compared with the measured hot spots 3 out 5 theoretical hot spots are confirmed (see table 4). The calculated ampacity of the 2 most limiting hot spots are better taken into account real time conditions.

HDD	Max. load (A)	Total hot spot time
HDD CS191	1329	6 days
HDD CS172	1330	0 days
HDD CS174	1336	40 days
HDD CS121	1351	62 days
HDD CS180	1386	60 days

Table 4: overview of measured hot spots
(with confirmed hot spots marked in bold + red)

For HDD CS172 the exact value of the thermal resistivity (wet) was unknown and therefore set to 1 K.m / W as an assumption for the thermal calculations. In reality this value is lower which explains this HDD appears not in the top 5 list.

For HDD CS191 the thermal resistivity seems to be much lower as expected and is currently further analyzed.

Final recommandations

The installation of the RTTR system on the Elia grid was done by the end of 2014. During the preparation and installation communication, cable and IT related problems were tackled. The key factor to success for an efficient integration in the Elia grid is the early involvement and collaboration between different experts: IT, cable and data communication.

Since the lifetime of a cable is very long, the RTTR is also used for a long period. The RTTR software is installed on a server and clear agreement about updates and upgrades of the RTTR software could guarantee the use of the software over a long period.

In order to improve the accuracy of the entire RTTR system several actions should be taken and planned after the installation: adjustment of the thermal zones, verification of communication paths & hot-spot analysis.

Next actions

Elia plans several actions & RTTR studies during the period of April-December 2015.

Overview of the planned internal actions:

- Use of the RTTR system for Grid Operators
- Double flexible connection at Koksijde

Overview of the planned RTTR studies:

- Analysis of the most critical hot-spot in the connection.
- Analysis of all the horizontal drillings.
- Analysis of all the road crossings.
- Analysis of the remaining laying configurations.
- Analysis of the losses in the cable.
- Analysis of the output values for the Grid Operators

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GLOSSARY

EMS: Energy Management System
GIS: Gas Insulated Switchgear
HDD: Horizontal directional drilling
TSO: Transmission System Operator
AAAC: All Aluminium Alloy Conductors
UPS: Uninterruptible Power Supply
GUI: Graphical User Interface
RES: renewable energy sources