Close and Return

ONLINE AMPACITY DETERMINATION OF A 220-KV CABLE USING AN OPTICAL FIBRE BASED MONITORING SYSTEM

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ABSTRACT

A dynamic rating system to increase the ampacity of a 220-kV power cable is described. The advantage of the used system is the ability to online calculate the ampacity and therewith to use short term ampacity increases in the operation of the grid. Measurement results are analysed and interpreted. Compared to the formerly installed static rating of the cable the use of the new monitoring system delivers additional ampacity depending on the current load and the soil temperature. Additionally the condition of the cable concerning cable temperature hot spots is monitored continuously.

KEYWORDS

Online monitoring, dynamic rating, ampacity, 220-kV underground cable, cable temperature

BACKGROUND AND MOTIVATION

The ampacity of underground cables is limited by the maximum allowable temperature at the surface between conductor and insulation (90°C for the 220-kV cable Siems-Luebeck). The cable heats up due to the losses (electric and dielectric) occurring during operation. The preload has significant effect on the temperature because of the cable's high heat capacity.

The foundation of the cable has to ensure an effective heat transfer between the cable and the surrounding soil. A desiccation of the soil has to be avoided, even in unfavourable conditions. During project planning conservative assumptions related to soil desiccation were taken. The ampacity of the cable is obtained considering the earth desiccation assumptions.

According to this the ampacity of an underground cable depends on the internal temperature of the cable (conductor temperature). The maximum allowable temperature of 90°C is indicated by the manufacturer. According to manufacturer's information this temperature is reached with a current load of 850 A. This corresponds to a planned cable power of approximately 350 MVA, which is based on conservative picked data for soil desiccation and the thermal conductivity of soils.

During operation the soil will periodically be more humid than assumed and therewith the heat transfer in average will be more efficient than designed. This leads to periodically higher ampacities than planned. Using a cable monitoring system the cable sheath temperature is recorded in regular time frames. The data is used for online calculation of the additional ampacity potential.

In the upper phase of the cable system optical fibre cables are integrated in the cable sheath to measure the temperature (Fig. 1).

In the past a Distributed Temperature Sensing (DTS) Monitoring System without online ampacity determination (dynamic rating) was used. Current and temperature data has been evaluated periodically to avoid a long term rise of the temperature level and to identify further increase possibilities of the cable ampacity. It has been shown that the ampacity of the monitored 220-kV cable could be increased from 850 A to 950 A as a static rating. This corresponds to 38 MVA or respectively an increase of 12 % [1].

Currently a DTS Monitoring System by AP Sensing is used. In combination with a dynamic real time temperature rating (RTTR) software, which is embedded in a visualization and communication software by OSSCAD, the ampacity is calculated online depending on actual load and surrounding conditions. The dynamic rating software is based on the IEC 60853. The additional ampacity obtained with the real time rating, the integration into the control centre and the calculation of the ampacity will be explained and presented in this paper.

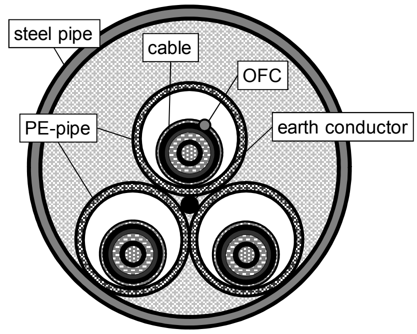

Fig. 1: Arrangement of cables in a steel pipe and optical fibre cable (OFC) in the sheath

DTS TECHNOLOGY

DTS technology has been introduced to the market place in the early nineties. A technique span-off from the academic research utilizing the optical time domain reflectometry (OTDR) combined with measurement of diminutive RAMAN Stokes and Antistokes light [3]. As a result a spatially distributed temperature profile over several kilometres length is obtained by using a simple fibre optical cable. This and the high electromagnetic interference resistance make it very attractive to monitor the temperature of underground power cables.

The DTS technology evolved quickly overcoming technical problems which are linked to conventional DTS systems and defining the difference between a laboratory apparatus and a robust industrial product. The diminutive Stokes and Antistokes signal challenge the instrument design providing sufficient signal-to-noise ratio (SNR) to measure temperatures accurately. Conventional DTS-systems utilizing susceptible Q-switched lasers (i. e Nd:YAG) with an optical power of hundreds of milliwatts to improve SNR. Disadvantages of degradation (reduced life-time), high cooling efforts and measurement instability are discretely tolerated. Furthermore due to SNR a conventional DTS-system measures Stokes and Antistokes signals simultaneously necessitating two independent receiver parts. Inevitable ageing of electrical components lead to a drift in the receiver's response and thus in drifting of temperature measurements. Consequently conventional DTS-systems are subject to recalibration after few years of operation.

In this project an AP Sensing *Linear Power Series* with 12 km range and two measurement channels is used to measure the sheath temperature of the 220-kV cable over a length of about ten kilometres. The decision is based not only on the robust industrial design and quality but on the proven low total cost of ownership (TCO).

Here the instrument SNR is significantly improved using a new correlation technique employing codes with complementary autocorrelation properties [3]. The instrument design is based on a low power semiconductor laser with low optical output power (< 20 mW) for a long life span. The code correlation concept enables a long measurement range combined with accurate temperature resolution. The improved SNR allows a single receiver design which ensures measurement stability by eliminating any drift effects and thus contributing to the low TCO.

Due to the low power consumption and related heat dissipation the instrument provides a wide operating temperature range from -40°C to + 60°C and allows robust operation even in harsh environments.

The DTS system (Fig. 2) is fully self-controlled and does not need any maintenance. The low cooling requirements facilitates an instrument design without any visible fan and consequently there is no need to replace filters which is required with other DTS systems from time to time.

Fig. 2: AP Sensing *Linear Power Series*

DYNAMIC CABLE AMPACITY RATING

The operation of most cable systems is characterised by regularly repeating load curves (often with a 24 hour cycle). Temperatures remain stable and the maximum allowed conductor temperatures are generally not reached. Operation with a static rating and a fixed ampacity is common. To operate the system safely and reliably it is important to know the maximum conductor temperatures and currents.

DTS systems allow the continuous monitoring of the sheath temperature. In combination with intelligent RTTR and visualization software the user is aware of the current thermal condition and the ampacity of the cable system. Consequently the operator can react appropriately on any overload or other environmental influences at any point along the cable run.

OSSCAD, a German company, has developed RTTR cable monitoring software for buried power cables which allows safe operation of the system (in accordance with IEC 60287) and takes into account the possibility of dynamic operation of the system (in accordance with IEC 60853).

The software concept is based on server-client architecture. The server is used for importing and storing DTS measurement data (sheath temperature and ambient temperature) and electric current data (conductor current), for measurement data processing, for RTTR modelling and for RTTR calculations. The purpose of upstream measurement data processing is to determine the location and temperature of maximum sheath temperatures (hot spots) along the cable run as well as to calculate the ampacity. These figures are required for subsequent RTTR processing. Fig. 3 gives an overview over the software concept as used in the cable system in Siems.

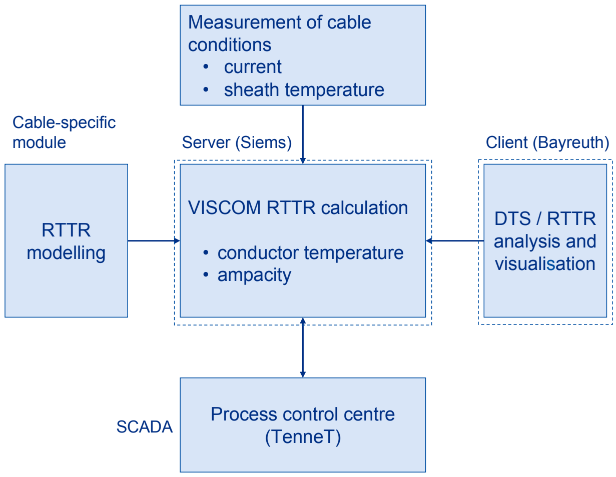

Fig. 3: System components of the RTTR VISCOM Software

The base of the RTTR calculation is the modelling of the cable system. The cable-laying requirements such as the laying depth, the thermal conductivity of the soil, type of earthing, and the operating conditions such as voltage, frequency, maximum permitted conductor current, etc. are stored on the server and made available for the use in RTTR calculations as a cable-specific module. The measuring time of the DTS system in the Siems system is adjusted to 15 minutes. Based on the measured temperature data the maximum sheath temperature (hot spot) is calculated and visualized, together with the online measured conductor current and the calculated ampacity of the RTTR calculation.

Normal Operation:

During normal operation of the cable system, the RTTR software calculates the ampacity leading to a conductor temperature of 90°C. The calculation considers the current sheath temperature and the current thermal cable load. The measurement data and the calculated RTTR data can be viewed in different formats depending on the application using the VISCOM Client Software.

Close and Return

For example, the system can be viewed as a diagram with temperature zones (asset zones) which represent the thermal load of the cable system (see Fig. 4). The asset zones represent the temperature measurements of the technically-relevant sections of the monitored cable system. The colour of the zones can be freely configured to switch from green to orange and red. The 3D visualisation shows the spatial resolution of the cable temperature over time along the power cable by means of RGB colours (see Fig. 5) giving the user a rapid overview of the thermal condition along the whole cable system over a longer time period (e. g. quarterly figures).

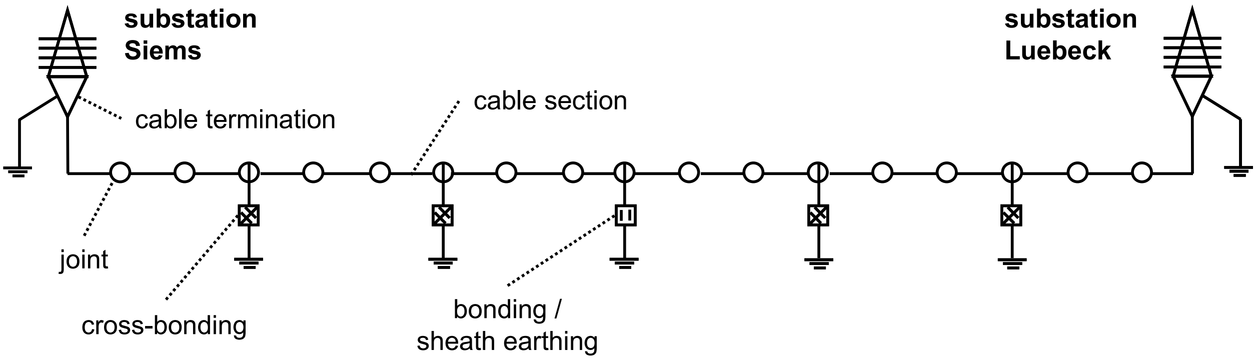

Fig. 4: Example of VISCOM visualization: Asset picture with freely-configurable asset zones

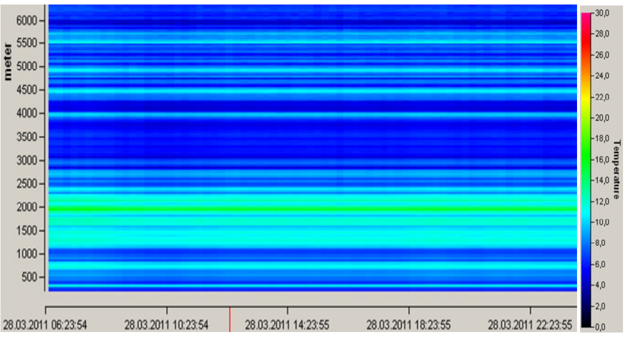

Fig. 5: 3D visualisation detail of changes in cable temperature along the power cable (location and time)

Emergency Operation:

When a cable system is suddenly charged with an additional load, the following points are of interest for the operator:

1. Maximum ampacity for a given period of time
2. Conductor temperature for a given current and time

VISCOM Client Software calculates the desired ampacity or conductor temperature for emergency operation. In addition to the data available for normal calculations the time period has to be entered. The RTTR calculation is then done on the server so that the results are transmitted to the client.

DATA ANALYSIS AND INTERPRETATION

The following figures show evaluations of the RTTR data collected during operation of the cable system from January 15th 2011 to April 4th 2011. In Fig. 6 the sheath temperature and the calculated conductor temperature over time are shown. During this period a maximum conductor temperature of approximately 35°C was reached. The conductor temperature is calculated depending on the sheath temperature and the actual current load of the cable. As shown in [1] hot spot temperature and minimum temperature along the cable length can vary between 15 and 20°C. The difference between sheath temperature and conductor temperature is 5°C maximum.

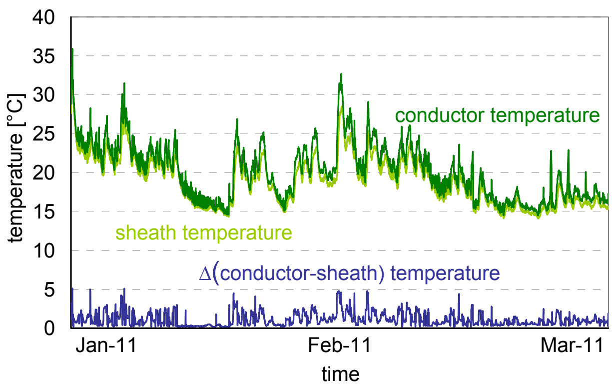

Fig. 6: Maximum conductor and sheath temperature over time

Fig. 7 shows the corresponding current that heated up the cable. Maximum values reach up to 800 A and do not reach the actual ampacity limit of 950 A. The frequency distribution of the current is given in Fig. 8 and it shows that the cable is loaded with an average value of about 300 A. The calculated ampacity is also shown in Fig. 7. It varies between 1,000 A and 1,600 A. Utilizing the online ampacity calculation may give additional flexibility to the control centre.

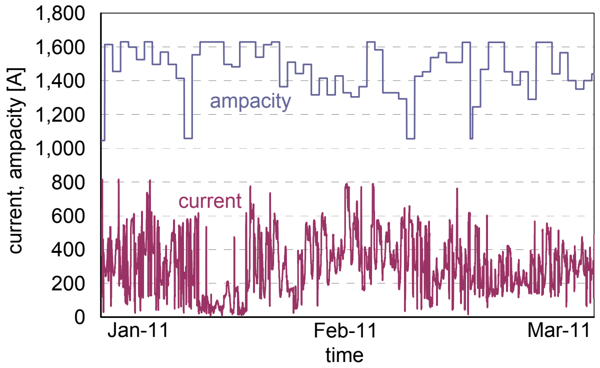

Fig. 7: Ampacity and current over time

The frequency distribution of the ampacity (Fig. 8) generally demonstrates the availability of additional ampacity. Compared to the static rating approach resulting in an ampacity of 950 A, loads up to 1,600 A are possible by using the dynamic rating. To enable the utilization of the additional ampacity it is necessary to integrate the calculated ampacity values into the existing Supervisory Control and Data Acquisition (SCADA) system. The influence of higher loads and therewith higher cable temperatures on the ageing and life-span of the cable has to be discussed. Today the maximum possible ampacity is limited by the transformer's congestion rated current of about 1,140 A. According to the frequency distribution an ampacity of 1,140 A was available 95 % of the time. It has to be taken into account that only the temperature values from the winter season have been evaluated. A lower ampacity during the summer can be assumed caused by the warmer soil.

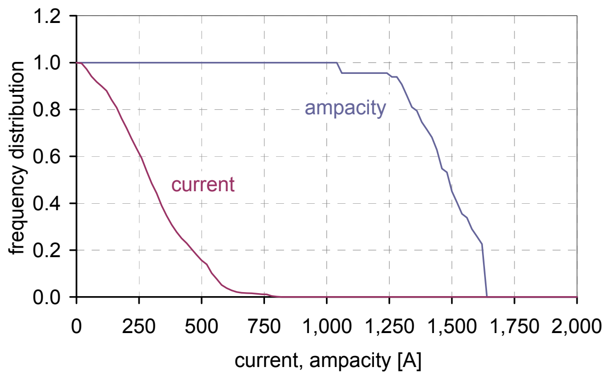

Fig. 8: Frequency distribution of current and ampacity

Fig. 9 shows the hot spot distribution along the cable length. Obviously there are two main hot spots at about 2 km and 9 km. The hot spot at about 2 km can also be seen in the Fig. 5. The difference between the hot spot temperature and the average temperature of the cable is in the range of 5 to 10°C. This means that the location of the hot spot does not significantly influence the ampacity of the cable.

The temperature of the hot spots has to be evaluated to analyse any changes that might occur in the absolute value of the hot spot temperature and to avoid a long term rise of the temperature level.

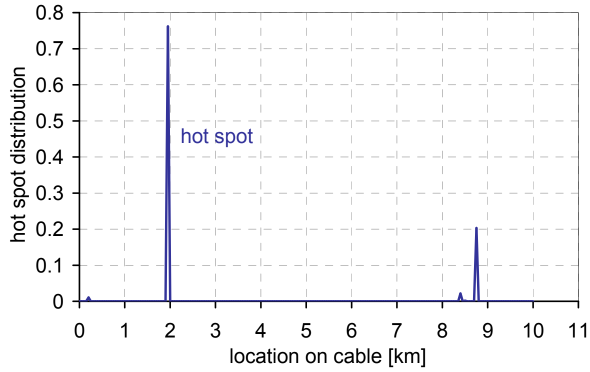

Fig. 9: Distribution of hot spot location

CONCLUSION

To enable the dynamic rating of the 220-kV cable a real time monitoring system has to be installed, tested and integrated into the existing SCADA system. The AP Sensing system was successfully installed and is in operation for three months. The evaluation of the measurement data shows the general operational reliability of the system. Compared to the static rating of 950 A evaluated by the old measurement setup the new system delivers an online calculation resulting in higher ampacities. This may be due to the winter season since the soil temperature is lower than in the summer season. Final statements on the ampacity level using the online monitoring system can be given at the earliest after a period of one year.

The advantage of the online, dynamic rating system is the continuous determination of the ampacity. This allows the use of higher ampacities in the operation centre also for short time periods.

The next step is the integration of the online monitoring into the existing SCADA system.

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