TEMPERATURE MEASUREMENT ON OVERHEAD TRANSMISSION LINES (OHTL) UTILIZING SURFACE ACOUSTIC WAVE (SAW)

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***Abstract*--In the deregulated market of electric transmission power systems today and as the energy demand continues to increase, electric utilities are faced with the challenge of moving more power via existing lines. As a result, power utilities and system operators are currently looking for opportunities to increase the capacity of the existing OHTLs without increasing the risk of equipment or system failure due to higher loading and an accelerated aging of the transmission infrastructure. One approach to manage the reliable operation of these systems is to utilize modern monitoring techniques as a method to prevent unexpected system outages. On OHTLs the sag of the individual line is an operational and security concern, which directly relates to the conductor operating temperature. The conductor operating temperature is influenced by various conditions eg. line losses, ambient temperature, wind speed and direction, solar radiation and conductor material properties. During periods of high ambient temperatures, low wind speed and high electrical system load conditions, monitoring and analyzing regional areas of the transmission network can be essential to evaluate the actual conductor operating temperature for the purpose of optimizing the line capacity and to prohibit potential sag problems. For measuring the conductor temperature of an overhead transmission line a sensor, which will have approximately the same thermal behaviour as the conductor, can be mounted on the conductor. Due to the high electrical and magnetic stresses in the area surrounding the overhead transmission line, a purely passive SAW sensor is used. The temperature of the conductor at the point of installation can be measured and the data transmitted wirelessly by means of a radio frequency backscatter (radar principle) to a data collection point. Along the overhead transmission line, installed passive sensors observe the temperature of critical line locations allowing continuous monitoring of the line behaviour. The measuring principles of the SAW sensor, the involved radar system components as well as current applications are presented.**

I. INTRODUCTION

The situation in the electricity market is changing in the last few years. At the one side the electrical energy market in continental Europe was deregulated some years ago and at the other side the electrical energy consumption is still increasing at an average level in Europe of approx. 2 % per year. Due to the deregulated electrical energy market the EHV transmission lines are more and more used as transportation utilities for the “delivery” of electrical energy across the European transmission network (UCTE).

Fig 1. EHV overhead lines

At one side a high wind generation power is located in the north of Germany, where power consumption is relative low, and on the other side the bottleneck is the south of Europe (especially Italy). Furthermore less new OHTLs were built in the last few years, because it takes more time to fulfil the environmental and governmental laws and the regulated fees for energy transfer in a network decreases constantly. So the existing EHV overhead lines must sustain higher upcoming energy transfer at lower compensation prices. The EHV overhead transmission lines were mainly built in the early 60s and in the 70s of the last century according to the national and international standards. The sag of overhead lines are dimensioned at a specific temperature, which is commonly 60°C for standard ACSR (aluminium conductor steel reinforced) conductor, because the reversible tension of the conductor depends mainly on the temperature, when no additional external load eg. ice on the conductor. The rated current at a conductor temperature for e.g. 80°C is defined by specified environmental conditions like 35 °C, 0,6 m/s wind and usual solar radiation [4]. The approx. 40 - 50 years old aged conductors have been creeping by several mechanisms, which are discussed in several papers [5], [6].

In the past the grid was designed for a load of 30%…50% of the rated current and the rated temperature was reached only in specific cases. But in the last few years the load of the OHTLs is increasing due to the discussed points up to the rated values. So the knowledge of the overhead line temperature is necessary for the decision of the transmission line loading, because due to the increasing load of overhead lines the sag is maximized and the clearance is minimized respectively.

Temperature measuring systems available for this purpose are rare and the appliance must be proofed. Various systems need a galvanic connection to the sensor, which is not possible at high voltage overhead lines and other systems don't fulfil the range of the environmental conditions.

These problems can be overcome with the use of passive SAW sensors.

II. SAW TECHNOLOGY AND ITS APPLICATION FOR OHTL (SENSOR)

A. SAW Technology

SAW elements are well known used as narrowband filters, as RFID tags and as wireless measuring sensors for torque, force, temperature and tension in various applications in the past. So these sensors could be use for temperature measuring at high voltage OHTLs, because instead of a galvanic link a radio link for the connection between sensor and measuring unit is used.

In fig. 2 the working principle of high frequency measuring system based on the SAW principle system is shown. A high frequency electromagnetic wave at the 2.45 GHz ISM band is transmitted to the sensor by use of a the transmitting antenna of the measuring system. By using the transducer, which is connected with the sensor chip, the incoming high frequency signal is transmitted to a acoustic surface wave, which is dispersed along the surface of the crystal. At several positions parts of the signal are reflected on integrated reflectors. The reflectors position is changed due to temperature elongation of the crystal. Also the propagation velocity of the acoustic surface wave depends on the temperature. The reflected signals are converted to high transmission frequency by the transducer and sent back to the receiving antenna of the system. The information of the sensor ID and the temperature information can be determined by the reflected impulses using various algorithms, which compute this information using the time position and the phase relation of the reflected impulses by common use signal processing techniques at a DSP. The results can be displayed at a personal computer.

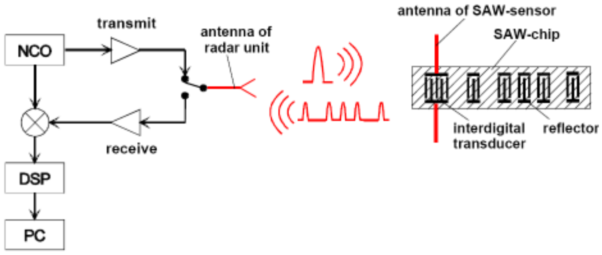

Fig. 2 Working principle of the high-frequency temperature measuring system based on wireless passive SAW temperature sensors (NCO = Numeric Controlled Oscillator, DSP = Digital Signal Processor, PC = Personal Computer) [1]

The SAW sensors are used for long term field tests in various applications in the field of high voltage engineering. The field tests with metal oxide surge arresters started 1997. After positive results with this measuring technique the system was also installed at various OHTLs and substations.

B. Sensor antenna

The fixing position of the sensor is shown in fig. 5 So the sensor can move at an ellipsoidal curve, which can be principle split up in two directions

- direction along the conductor, which can be influenced by sag variation, wind, temperature of the overhead line (approx. angle ±15°)
- direction perpendicular to the conductor, which is mainly influenced by wind (approx. angle ±45°)

For this situation an easy and robust suitable antenna was developed with a gain of approx. 5 dBi and an accepting angle of approx. 60° x 60°. The polarization is vertical.

C. Sensor clamp for fixing the SAW sensor at OHTLs

To apply such a sensor with the antenna to an OHTL a special clamp was developed. The development requirements of the clamp can be summarized as follows

- housing of the sensor tag
- housing of the sensor antenna
- easy to install
- long time stable connection

According to these points a clamp with helical fixing is used for easy installing and reliable connection of the sensor clamp at overhead line. This fixing technique is already used for many years for fixing vibration dampers and spacer dampers at OHTLs. Furthermore this fixing technique is used for OPGW fittings from the 1980s till now on. So far more than 50.000 vibration dampers and spacer dampers are installed worldwide. The sensor and the sensor antenna are covered by a PTFE enclosure (fig. 3)

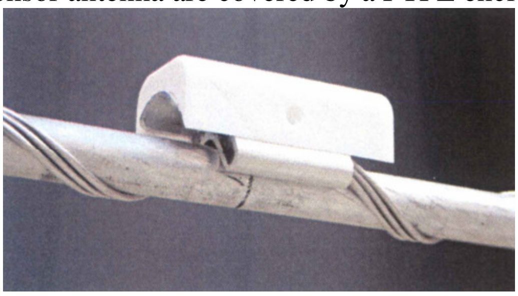

Fig 3 sensor clamp

This sensor was tested in a high voltage laboratory for fulfilling the national and international standards for riv according to IEC 61284 (requirements and tests for fittings), which passed the test for single line 123 kV and 245 kV and triple bundle conductor for 400 kV. In fig. 4 the sensor clamp at 240 kV at a single conductor is shown, where the first streamer discharges could be recognized.

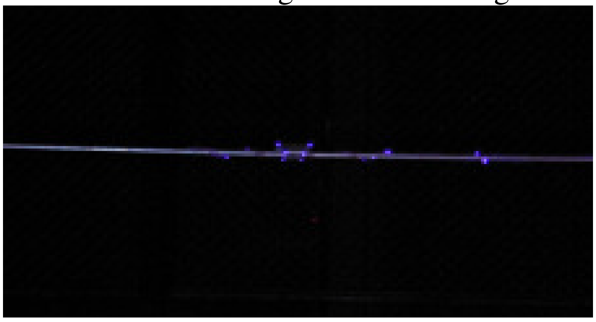

Fig 4: riv test of the sensor clamp at 240 kV

III. DESCRIPTION OF THE SYSTEM

The EHV overhead line online temperature monitoring system consists of measuring unit at the tower, a database server at the e.g. substation and the data communication.

A. Components at the tower

At tower the measuring station is installed (fig. 5). Above the conductor the two tower antennas (transmitting and receiving antenna) must be fixed at the optimal angle to the sensor by using a telescopic sight. The sensor must be fixed at a distance of approx. 2 m from the fitting of the suspension string. The radar unit box is mounted close the tower antennas to minimize the losses at the high frequency connection with cables. For the power supply two solar panels are fixed at the top of the tower. The control unit is installed at the bottom of the tower or at a specific height for protecting for vandalism. The control unit consists of the charge control for the batteries, the batteries, a controller board and the GPRS modem for data connection. The control unit is connected with the radar unit box by using fiber optic link cable.

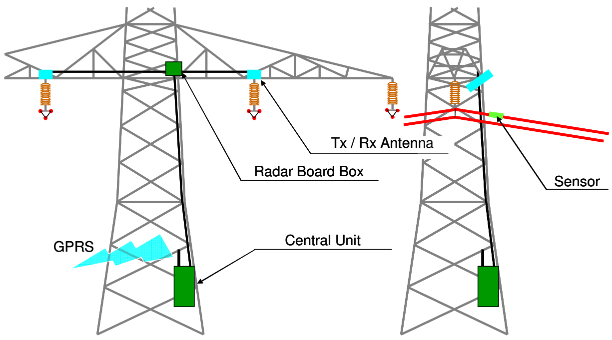

Fig 5 Components at the tower

B. Installation at the substation and reporting software

At the substation a GPRS modem is installed at a personal computer, which is used as data collecting and data server system. The communication between the measuring station and the personal computer uses the TCP/IP protocol, it is encrypted and is used in a bidirectional way. The measuring station can be fully controlled and configured by the software at the personal computer. The reporting software can be used from each personal computer, which is connected to the data server.

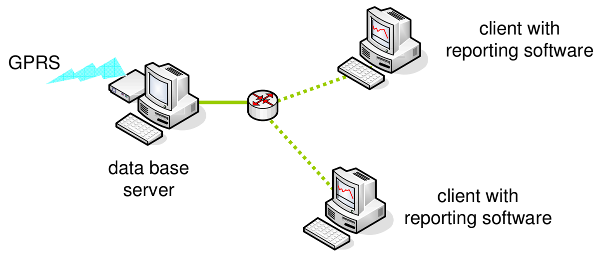

Fig 6 Installation at the substation and usage of the reporting software

IV. EXAMPLE FOR AN INSTALLATION OF THE SYSTEM

The first installations of this system were done in the end of the last year, whereby the data acquisition works stable at various environmental conditions e.g. at high wind, snow and rain fall, fig. 7 shows, an example for the installation of the temperature online monitoring at a 400 kV line.

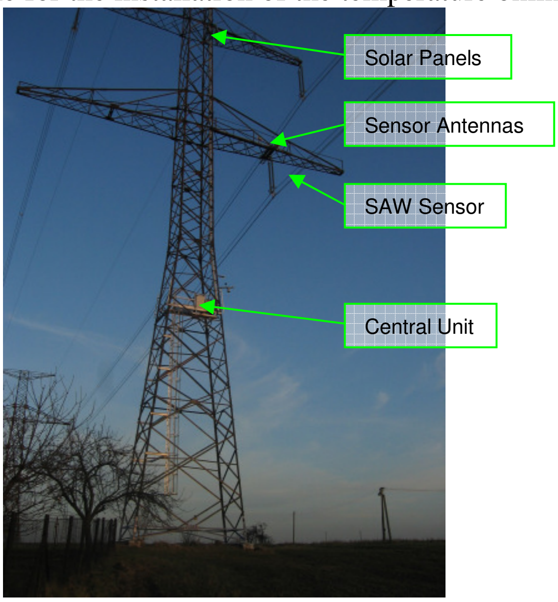

Fig 7 Example for the installation of the system

V. FURTHER INVESTIGATIONS

The online measuring unit measures the temperature of the sensor. The conductor temperature is the result of the flowing to and effluent thermal power. The ambient conditions, which affect the conductor temperature, are the current, the wind velocity, the angle between the conductor and the wind direction, the global radiation, the solar radiation and fluent cooling mechanism. These components have different influences on the conductor and the sensor, but both are influenced by the same factors. In general the measured sensor temperature is not equal to the conductor temperature because the sensor is a heat sink in this complex thermal system. So the conductor temperature must be computed by using the measured temperatures of the sensor. For this purpose a calibration of the sensor and conductor must be made in the laboratory.

VI. SUMMARY

Due to the circumstances at the changed market of electrical energy new monitoring systems for overhead lines are necessary. The well-known SAW technology can be used for this application easily. The sensors are passive and can withstand the common transient and power frequency stress on a OHTL. For the usage at overhead lines a suitable clamp, which can be easy installed and fulfill the mechanical and electrical requirements, was designed. The data acquisition unit was designed for the rough requirements for installations at EHV overhead line towers, which are supplied by solar radiation. The data server is conceived as a flexible and stable system with flexible usage for power grid operators. The first installations of this system were done in the end of the last year. In a further work the development of the computation of the conductor temperature is done. It could be shown, that the used developed system, can be easy used for retrofitting existing overhead line towers and the measurement of the sensor temperature works at various environmental conditions.

VII. ACKNOWLEDGEMENT

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IX. BIOGRAPHIES

Christian Bernauer was born in St. Pölten, Austria, on July 20, 1960. He graduated from the technical University of Vienna. He is responsible for Engineering and Marketing at the RIBE company. His employment experience includes Alstom and Siemens in the field of Air insulated high voltage disconnectors.

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Sacha Markalous, born in 1975 in Germany, ended his studies of electrical engineering at the University of Stuttgart in the year 2002. He did his PhD in the area of Partial Discharge measurement with the focus of locating Partial Discharge. Since March 2006 he is with Lemke Diagnostics, Dresden where he is responsible for product development.

Michael Muhr, born 1944 in Austria. Since 1990 Head of the Institute and Director of the Test Institution of High Voltage Engineering of TU Graz. He is a member of IEEE, IEC and CIGRE. Cooperations with institutes in Czech Republic, Poland, Slovakia, Croatia, Slovenia, China, India as well as industry and utilities.

Thomas Strehl graduated as Master in Electrical Engineering. At the Institute of Electrical Power Engineering of the Technical University Berlin, where he was involved in research and teaching in the field of partial discharge diagnostics and electromagnetic compatibility. In 1999 Thomas Strehl was appointed Managing Director of LEMKE DIAGNOSTICS GmbH in Germany. He is member of CIGRE, IEEE. In CIGRE he works as a convener of TF 2 for D.1.17 and he is the secretary of D1.33 “High Voltage and High Current Test and Measurement Technique”.