A new method of direct icing measurement on HV electrical lines

Jaroslav Šabata[1], Petr Lehký[1], Petr Vaculík[2]

[1] *EGÚ Brno, a. s., Czech Republic*
[2] *E.ON Distribuce, Czech Republic*

jaroslav.sabata@egubrno.cz, petr.lehky@egubrno.cz, petr.vaculik@eon.cz

Abstract—**EGÚ Brno, in cooperation with E.ON Distribuce, launched a new project of direct icing measurement on electrical lines several years ago.**

The idea was to provide dispatchers with immediate information about ice formation on the conductors of lines. The paper will describe the method which was designed for this measurement. Such method allows to on-line monitor the situation of icing occurrence on the line. Data gained from the measurement are integrated into Automated icing monitoring system. First installations in the real network and results obtained from the operation of direct icing measurements will be shown and discussed.

Finally, next development of this project will be outlined.

Keywords— ***Overhead line, Icing measurement, Distribution System Operator (DSO), Conductor heating, Tension***

I. Introduction

As mentioned in our other paper "Automated Icing Monitoring System", for the measurement of icing PMS stations are employed. The measurement of ice load provides information about icing creation in a given location. Except ice load PMS station monitors the following meteorological parameters: temperature, wind speed and direction, relative humidity and, optionally, solar irradiance. This system of icing measurement is used on the whole territory of the Czech Republic and west part of Slovakia. Information on icing occurrence in an area is far most used by dispatchers.

DSO E.ON Distribuce operates about 1 000 km of overhead hv (110 kV) lines in the areas, where can be affected by icing. To protect 110 kV lines from heavy ice loads DSO E.ON Distribuce has been using heating of some these lines for a few decades. In recent years information about icing occurrence from a PMS station has been the signal for dispatchers to start preparing hv lines for heating in such an area. To provide dispatchers with more precise information about icing formation we have proposed a method of direct measurement of icing load on the conductors of hv lines.

II. Testing phase

To measure the tension in the conductor we have chosen force transducer (sensors) from German company HBM. Its operating temperature range is from -30 °C to +85 °C. The body of the sensor is made of stainless material and does not require any maintenance.

Testing of the sensor was carried out on a single conductor at Studnice test station. The sensor was mounted at the middle tower in the conductor support (Fig. 1). The main goal was to test the stability of the sensor, resistance to harsh conditions and on-line communication with SQL server at EGÚ Brno.

The measurement installation was realised in autumn 2014 in order to carry out measurements during the winter season.

Fig. 1: Force sensor at Studnice test station

The results we obtained were very encouraging. The measurement from the sensor was stable for the whole winter period. Output values on the graph shows the beginning of the icing cycle, as it was recorded by the sensor (Fig. 2). Small disturbances around midday are due to the wind.

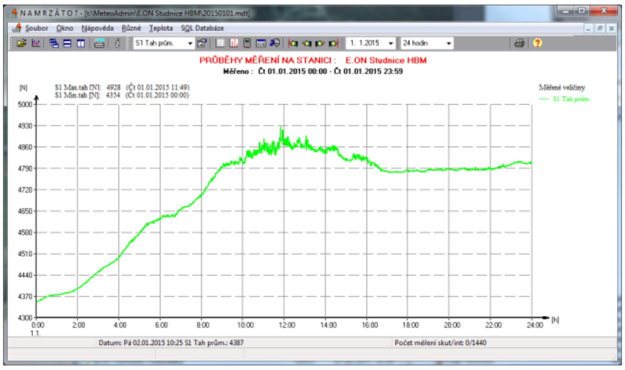

Fig. 2: Beginning of icing cycle measured by force sensor

III. Method of direct icing measurement

While at test site Studnice the sensor measures (as can be seen from Fig. 1) directly the weight of the conductor (and of icing), on the real line the sensor is mounted at the anchor tower into the anchor chain. It means the sensor measures tension in the whole anchor span. By knowing mechanical parameters of the conductor, length of the anchor span, meteorological conditions and other parameters we are able by means of special software recalculate measured tension into ice load in kilograms per meter on the conductor.

IV. Pilot Project

After the sensor was successfully tested, a pilot project of the first installation in the real hv network started to be prepared.

The 110 kV line anchor tower, located near village Ruda (about 50 km west of Brno), was chosen as the installation site, mainly for two reasons.

The first reason was that due to the icing created in this area in December 2013, part of the 110 kV line was damaged (Fig. 3). As this part of the line had to be rebuilt, all the system of measurement was easier to design and install.

Fig. 3: Collapsed anchor tower

Second reason was close proximity of PMS Ruda (approx. 1,2 km). The close distance of this PMS was supposed to allow us to compare the icing load, measured at the 110 kV line, with the icing load obtained from this station. Climatic data from this station is also used to calculate ice load.

The installation of the entire measurement system was carried out in three days (21 – 23 September 2015).

In Fig. 4 location of PMS Ruda and the anchor tower is indicated. The red line shows the anchor span, in which the tension is measured. The length of the anchor span is 1 389 m.

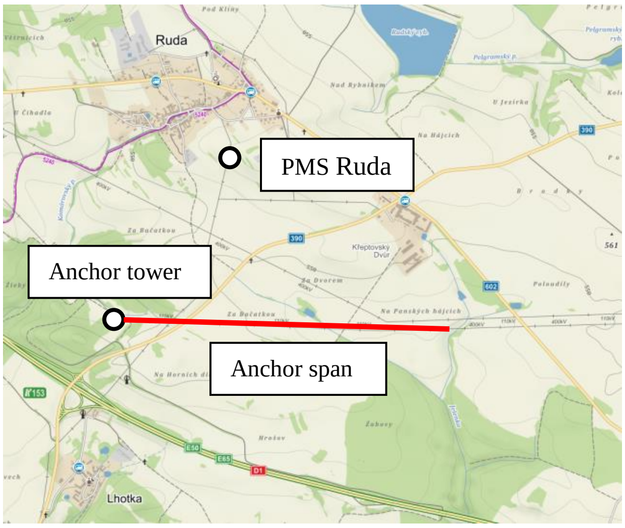

Fig. 4: Location of anchor tower and PMS nearby Ruda village

A. *Design*

The concept of measurement is based on the proven concept of PMS stations (electronic components, data management, communication, etc).

The whole measurement system consists of the following parts:

- Sensors
- Set of two solar panels
- The box with the central unit and with the source part including two accumulators
- Sub-racks with protections and filters.

The disposition of the automated monitoring equipment on the anchor tower can be seen from Fig. 5. On this picture positions of six sensors into individual conductors are labelled. The central box is located on the tower base, solar panels are mounted below the lowest phase conductor.

All system components (solar panels, central box, sub-racks, cable connecting box with solar panels and cable connecting box and sub-racks) are located at a safe distance from the conductors, allowing their maintenance or repair, or updating the firmware without limiting the operation of the line.

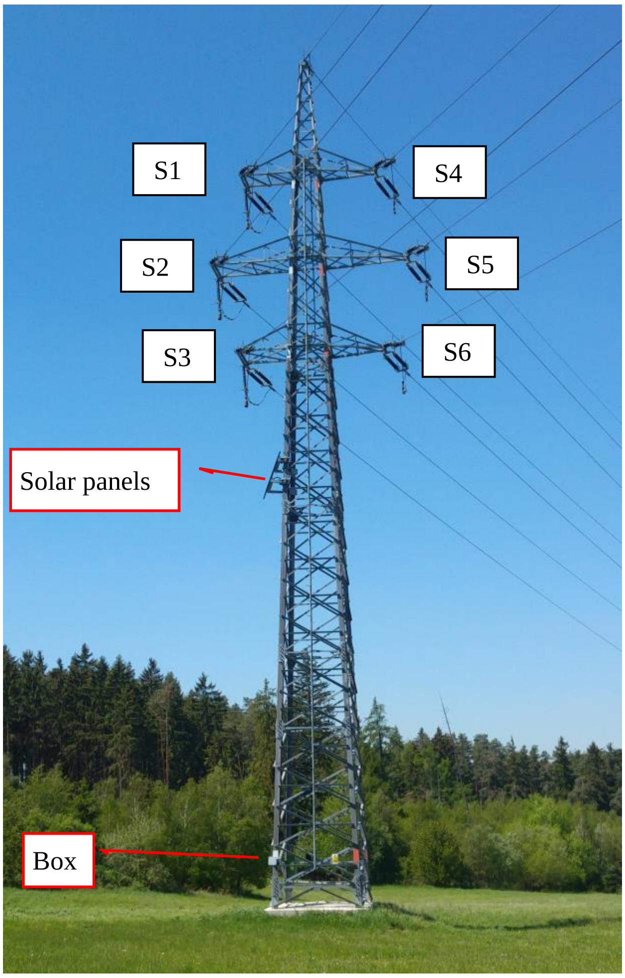

Fig. 5: New anchor tower with measurement

B. *Sensors*

The nominal force of the sensors was chosen according to expected load in anchor span.

This electrical 110 kV line is configured as double circuit line. It was decided to measure tension of each phase conductor, i.e. 6 sensors were installed. Attachment of the sensor into the insulator chain can be seen from the Fig. 6.

By installing the sensor into each phase, we have good information about ice formation on each conductor within the anchor span. When heating the line, ice fall off (at least in the anchor span) is clearly apparent.

Fig. 6: Sensor in the insulator chain

C. Power supply

The measurement system is powered by two solar panels (see Fig. 7) that charge two batteries.

The operational regime of the accumulators is controlled by the automatic system in the central box. The accumulators are charged via the charging controller that secures a permanent charging, protects against overcharging, prevents discharging through the photovoltaic module at time without sunshine and provides temperature compensation of the control voltage, depending on ambient temperature. The accumulator type used for providing the back-up supply, is maintenance-free.

Fig. 7: Set of solar panels

D. The measurement

Analog signal of the sensor is processed by an A/D converter, which provides the required strain gauge power supply, including supply line compensation and ambient temperature drift compensation. Analog signal is then transmitted via RS485 line to an evaluation unit, which is situated in the central box.

The evaluation unit provides following functions:

- processes a digital signal on the RS485 interface from the A/D converter
- enables parameterization of the evaluation unit itself and parameterization of the A/D converter via TCP/IP protocol
- archives daily files in binary format, which can then be processed.

The measured samples are processed each minute. Tension is provided as an average, a maximum and a minimum value of 30 measurements for every minute. The measured data are evaluated and then archived into daily files on the flash memory.

The data can be sent instantaneously (one-minute values), or as daily files (once a day), to the control system (SCADA or a SQL server).

E. Data transfer

It is possible to communicate with the unit either remotely via GPRS (central unit is equipped with a modem and a SIM card) or locally from the computer via Ethernet.

In this phase data are transferred only into SQL data server at EGÚ Brno, no transfer to SCADA system of E.ON is used (even though the IEC 101/104 interface for SCADA is incorporated).

F. Alarms

Central unit can generate and send alarms with transmitting them into the central computer (SCADA or SQL server). Alarms are sent immediately in the following situations:

- opening the central box door
- the loss of supply voltage
- voltage drop in accumulators below set point.

V. COMPUTATIONAL MODEL

The following input data is used to perform the calculation:

- tension, measured by sensors
- parameters of the line (length of anchor span etc.)
- parameters of the conductor (type, cross-section, modulus of elasticity etc.)
- meteorological data from PMS stations in close distance of the tower.

The model includes a special algorithm, which, based on all input data, calculate the ice load on each conductor (in kg/m). The ice load is calculated every minute.

Because the server in EGU Brno stores all the necessary input data into the SQL database (from the PMS stations and the tension in the conductors), the computational module is also running on this server.

The output values (ice load) are also stored in SQL database to be available for the users. As no communication link has been established between SQL server at EGÚ Brno and utilities SCADA system yet, users can see the values only via special Internet web page (the same web page, which visualize data from PMS stations).

VI. Results

For the presentation of measurement and calculation results, data from the PMS station Ruda and the aforementioned anchorage section of the 110 kV line located near this station are used.

It should be noted that the Ruda PMS station (Fig. 8) is located at an altitude of 560 m above sea level. An anchor section of the 110 kV line, in which the measurement of tension in conductors is installed, passes through a flat area with an altitude of approximately 550 m. Its orientation is east-west.

Fig. 8: PMS station Ruda

A. *Evaluation of an icing cycle*

The graph on the Fig. 9 shows record of tension, measured by the sensors S1 (green line), S2 (red line) and S3 (grey line) during 5-day icing cycle on December 2016 (disposition of sensors – see Fig. 5).

It can be seen this line was heated twice. First heating was done on December 21st in the afternoon, second heating of the line was carried out two days later, on December 23rd before noon. The first heating begun when the ice load on the upper conductor was about 1.5 kg/m (sensor S1 – green line). The dispatcher started the second heating when the ice load on the upper conductor reached the value approx. 1.2 kg.

From the course, the decrease in conductor tension to values before the icing cycle is well visible.

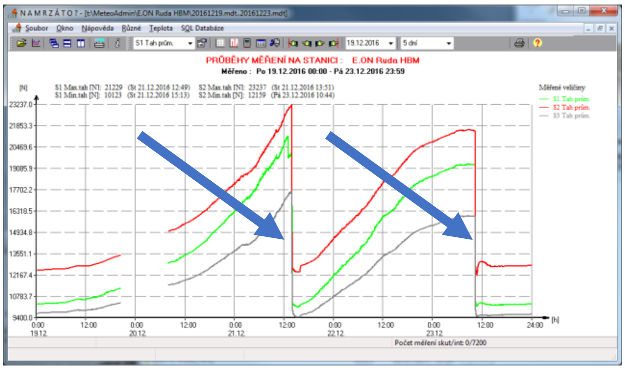

Fig. 9: Measured tension during icing cycle (S1-S3)

Fig. 10 presents ice load, recalculated by the model from tension values measured. After each heating cycle, the ice load is zero, indicating that all the icing has dropped off during heating in the anchor span.

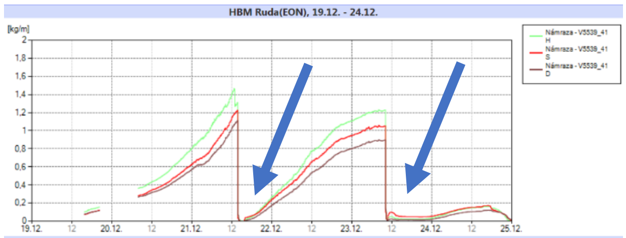

Fig. 10: Calculated ice load during icing cycle (S1-S3)

Ice load course on the conductors in which the sensors S4, S5 and S6 are installed is shown in shows Fig. 11. As can be seen from this graph, this line was also heated twice. Comparison of Fig. 10 and Fig. 11 shows that this line was heated in both cases a few hours earlier.

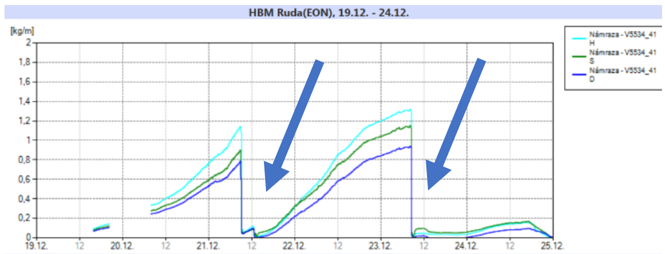

Fig. 11: Calculated ice load during icing cycle (S4-S6)

B. *Comparison of ice loads*

The close proximity of some PMS stations and the places where the tension measurement in the conductors was installed makes it possible to compare the course of the icing growth on the conductors and on the rod of the PMS station.

For comparison, one icing cycle was selected. The episode was recorded in December 2018. The comparison will be demonstrated in the following figures.

Fig. 12 shows the course of this icing cycle, recorded at PMS Ruda. Next Fig. 13 presents the course of icing growth on the individual conductors of the 110 kV line, determined by calculating from the conductors tensile. The graph also shows the height dependence of icing growth. The icing cycle lasted approximately 40 hours, and ended December 20 after midnight, when a sharp warming arrived (Fig. 14).

A good correlation between the two measurements can be seen from the comparison of the icing growth on both graphs.

It is also possible to compare the measured icing maxima from the graphs. At the Ruda PMS station, the measured maximum icing reached 0.6 kg/m (the measurement itself is about 8 m above the ground). The calculated maximums on the conductors in the anchor section range from 0.4 kg/m to 0.7 kg/, which is in good agreement with the maximum value, measured by the Ruda PMS station.

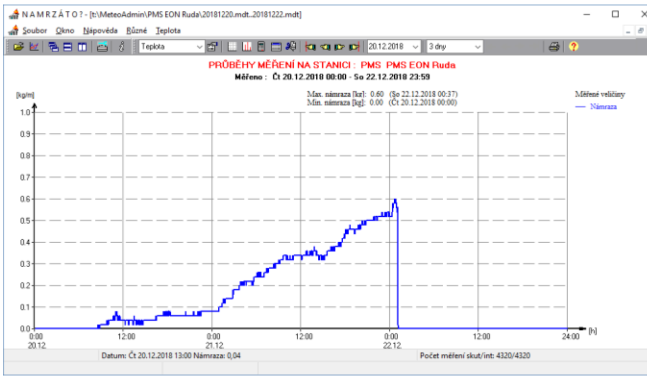

Fig. 12: Ice load measured at PMS Ruda

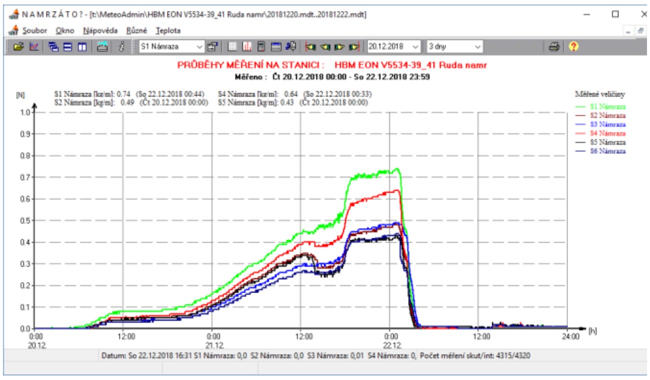

Fig. 13: Calculated ice load in the anchor span on the 110 kV line close to Ruda

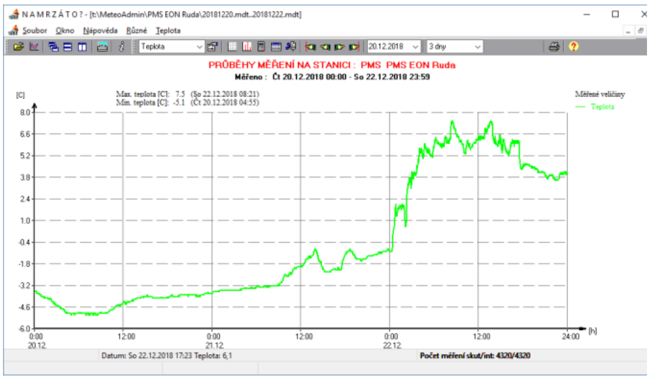

Fig. 14: Measured ambient temperature during icing cycle at PMS Ruda

C. *Evaluation of tension*

If necessary, the measured tension data in the conductors can be back-analysed. Example of the tensile values, measured during a day (May 8th 2019) in one of the conductors, presents Fig. 15. The graph shows the maximum (green curve), minimum (blue curve), and average (green curve) values.

The variance of measured tension values corresponds to the wind speed (see Fig. 16) that was measured during that day by the Ruda PMS station.

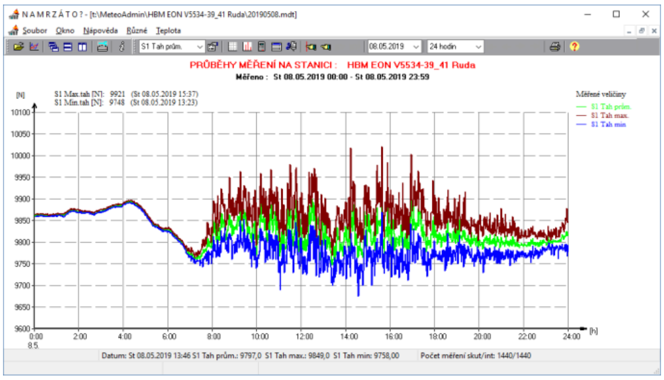

Fig. 15: Measured tension during

Around 10 a.m., the wind speed began to rise, reaching around 14 m/s.

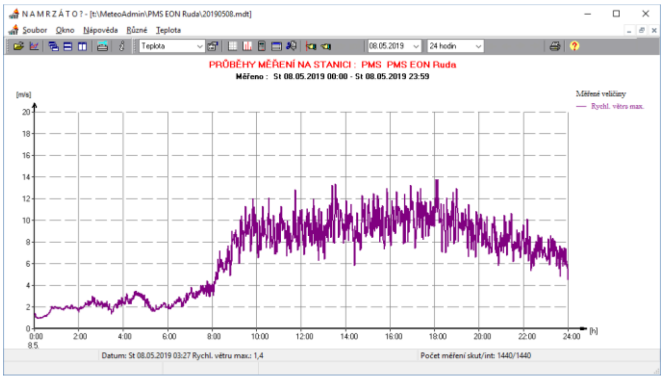

Fig. 16: Measured wind speed

There was also a change in wind direction from northeast to southeast (Fig. 17).

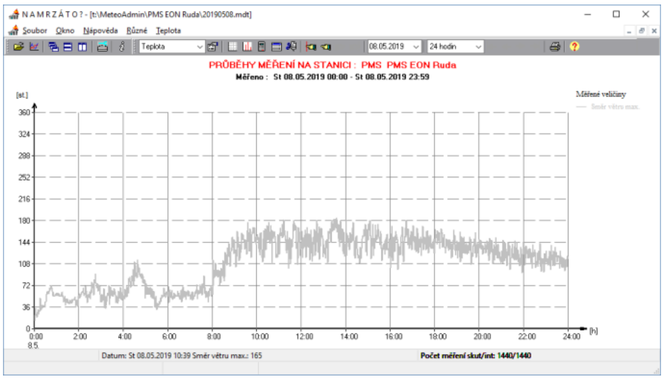

Fig. 17: Measured wind direction

The tension in the conductor is also affected by the ambient temperature (Fig. 18).

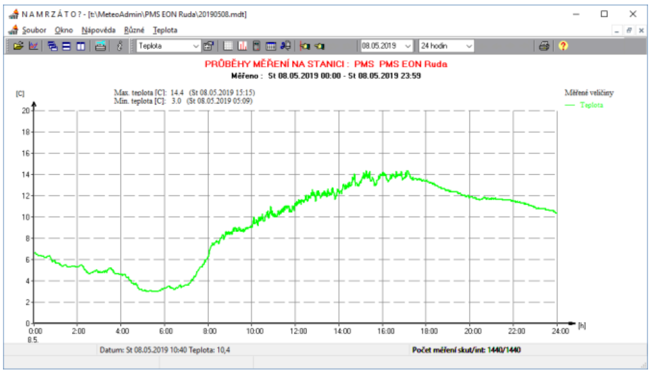

Fig. 18: Measured ambient temperature

VII. INSTALLATIONS

Since 2015, when first sensors nearby Ruda village were mounted, measurements have been installed at 9 locations (see Table I). As can be seen from Fig. 20, most installations are located in the area of Czech-Moravian Highland.

TABLE I. OVERVIEW OF HBM MEASUREMENTS INSTALLED

Company	Country	Nr. of installed	Place of installation	Year of install.
E.ON Distribuce (DSO)	Czech Republic	8 *+3*	110 kV lines	2015 (1) 2016 (1) 2017 (3) 2018 (3) *2019 (3)*
ČEZ (DSO)	Czech Republic	1 *+1*	110 kV lines	2018 (1) *2019 (1)*
Total CR		**9 + *4***		

The deployment of stations corresponds to the areas where icing usually occurs (Fig. 19, Fig. 20). Anchor sections on 110 kV lines are selected in collaboration with local technicians who have a good insight into icing creation in areas of interest. When selecting the tower, on which the sensors are mounted, it is necessary to take into account, for example, its construction, accessibility in the field or position (it must not be shielded by the surrounding vegetation due to solar panels).

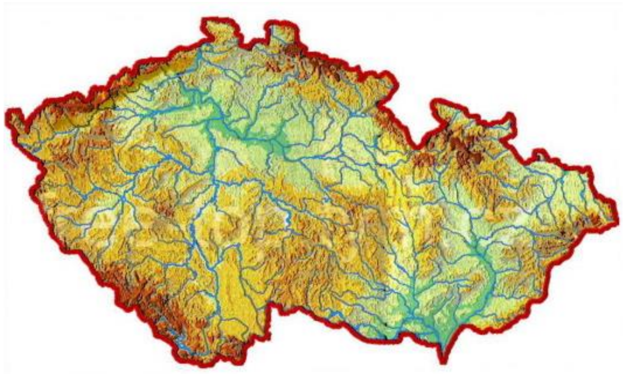

Fig. 19: Geographic map of the Czech Republic

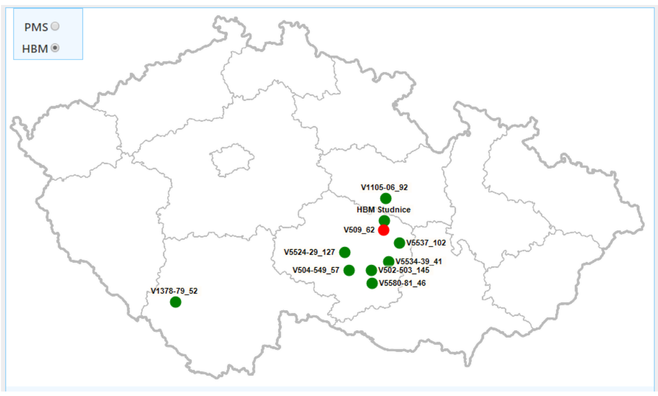

Fig. 20: Map with HBM measurement on the territory of the Czech Republic (current state)

VIII. AUTOMATED (ICING) MONITORING SYSTEM

As mentioned above, the tensile measurements in the conductors and the calculated ice load values are also included in the Automated (icing) monitoring system. This means that, in addition to data from PMS stations, these values are also accessible via a web page. This gives users access to all data that is measured by all PMS stations and HBM force transducers.

IX. OUTLOOK

This year, the monitoring network will be expanded by measurements in another 4 locations, one place is found in western part of the Czech Republic, the remaining three will be installed on the 110 kV lines located in Czech-Moravian Highland. The installation of further measurements will continue in the following years.

Also, ZSD utility, which operates a network of PMS stations in western part of Slovakia, is considering a pilot project of this measurement.

X. CONCLUSION

A new method of direct measurement of icing on electrical lines has been introduced in this paper. The aim was to give dispatchers immediate and precise information about icing formation on the 110 kV lines. From the point of view of the distribution system operator, it is therefore beneficial to have a comprehensive, full-area information system based on the current state of icing directly on the line conductors for a quick and reliable analysis. From this it is possible to deduce on which line icing grows faster. This makes it possible to decide in a timely manner which lines are needed to remove icing in order to avoid possible damage to the line.

In last four years sensors of tensile stress measurement have been deployed at few anchor towers of 110 kV lines on the territory of the Czech Republic. Such method allows on-line monitoring of icing formation on the line. Data gained from the measurements have been integrated into Automated icing monitoring system, which makes the data easily available to the users.

As the results show that the measurement is very reliable and provides useful information about ice load on conductors, it will be expanded to other locations.

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