Advanced monitoring of icing and prevention against icing on overhead power lines

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Abstract — **The aim of this paper is to present the investigation of complex icing system for the transmission grid. The introduced investigation forms a two-level method, which in the first stage gives a warning for system operators when the environmental factors are appropriate for ice formation on conductors. Then a mathematical model forecasts the radius and mass of the expected ice-layer. The mathematical relationship between the conductor's tensile force and sag is crucial for the calculation of the conductor's expansion (tension) and final length over a constant span distance. The reliability of ice thickness calculations mainly depends on the accuracy of conductor temperature and angle/sag measurements. The OTLM-ICE application enables the operator of the transmission network to monitor sag and clearance changes on a conductor, subjected to ice overloads. The operator can optimize and determine the suitable ampacity of transmission lines in order to prevent the damage in the early phases of ice-rain. The second level of the system monitoring the ice-formation on the phase conductors with line-monitoring sensors, thus the system operators get real information about the line condition. The operation of the methodology is also investigated, which are also presented through case studies. FLEXITRANTORE as a HORIZON 2020 project aims to develop an integrated platform for the next generation flexible electricity transmission system.**

Keywords — ***Overhead Transmission Line Monitoring; OTLM SMART; Temperature of Conductor; Sag of Conductor; Ice; Alarm; Tensile Force in Conductor, De-icing***

I. INTRODUCTION

After the catastrophic icing event at the beginning of 2014, when large numbers of low, medium and high voltage overhead power lines (OHL) collapsed particularly in the western part of Slovenia, a sophisticated development was initiated regarding advanced ice monitoring. Several hundred thousand of customers in this area of Slovenia have been out of electrical power supply for several days. The complete reconstruction of the damaged OHL network lasted several months. Distribution System Operators (DSOs) and Transmission System Operator (TSO) were forced to use provisional solutions at all levels of tension. The single important high voltage OHL has been successfully put into service using Emergency Restoration Systems (ERS).

Historical meteorological data indicate that the weather is becoming more and more extreme. For the electrical utility operators, DSOs and TSOs, these changes result in new operation challenges that need to be addressed. For example, frequent icing phenomenon affects all the components of the power lines by a significant mechanical overload: it endangers the conductors, the insulators and the towers as well.

The result is often fatal and besides serious failures, it effects operators' decisions. These not only endanger the reliability of electrical grids by the loss of a power line for weeks or even months but in general, the safety in the surroundings of the power line.

As technology advances, we will be able to collect, analysed and predict very large databases in the field of meteorology and electrical engineering. The ability of processing mentioned data, combined with know-how results in the capacity to operate power lines at their thermal limits during different ambient parameters. This technology, called Dynamic Line Rating (DLR) – is not only a great way to increase the transmission capacity of a certain OHL, but can also be effectively used to prevent, or even solve icing-related issues.

Higher currents result in higher Joule-heats, that consequently heat the conductors. If limits can be reached or approached, icing can be prevented. If prevention is not possible, the detection and removal of the ice layer is necessary. The proper handling of this icing issues requires advanced algorithms (expert systems) and reliable measuring equipment.

In order to the determine available capacity of electrical high voltage transmission lines, the distributor needs results about safety clearance and temperature of conductors. This was the initial mission of OTLM (On-line transmission line monitoring) SMART system, but catastrophic icing of transmission lines and towers in year 2014 in Slovenia, required also prevention against icing damage.

Therefore, the OTLM SMART software unit was updated with inclination angle measurement "inclinometer" and with new software features for determination of additional mechanical load of conductors due to ice or wet snow. Determination of additional mechanical load based on difference between measured angle and mathematically determined angle by model. Since angle of conductor is usually small (less than 10°) the measurement of conductor angle is challenging. In order to overcome the problem of accurate angle measurement the new expert system has been developed.

The newly developed expert system is based on the statistical analysis of collected data of on-line measurement in the long time period with a specific time interval of 10 min. The set of data at each temperature of the conductor includes the air temperature, humidity, current (A) and the conductor angle at the attachment point of the OTLM SMART device.

All measurements of the conductor's angles are statistically analysed at belonging temperature of the conductor in order to determine the mean value and statistical range at 99,97 % of probability. This is statistical relevant parameters, without any additional mechanical load of the conductor, are considered as initial statistical data. From the current set measurement, the expert system calculates new statistic parameters. Each new measured value of the angle is considered as a new added value in statistical analysis.

The Expert system compares both set, initial statistical data and new statistical data with additional value. The range of probability distribution overlapping provides the probability of ice on the conductor. The statistical analysis contributes to a better quality of compared values and provides higher reliability to measured values. The combination and synchronization between algorithms, weather service and measuring equipment is the key to the successful operation.

An EU H2020 financed project called "FLEXITRANSTORE" has been launched by the end of 2017 to develop a cross-country co-operation, with an objective to improve anti-icing and de-icing solutions. To establish and analyse different solutions, the project includes several universities, TSOs and DSOs.

To solve the mentioned icing issues, Budapest University of Technology and Economics (BME) developed an advanced neural-network based algorithm of DLR, which uses co-operates with the OTLM SMART software system. The University of Maribor, Faculty of Mechanical Engineering (UM FS) in cooperation with C&G developed in several steps a mathematical algorithm for sagging "OTLM-SAG" and for ice warnings "OTLM-ICE ALARM". Test equipment was installed to demonstrate the capabilities of these new technologies on the DSOs grid of Electro Ljubljana (ELJ). Besides the introduction of icing, this paper also focuses on the preparation and organisation of co-operation between different companies (industry) and universities.

II. ICE STORM IN SLOVENIA IN 2014

In the last thirty years, in the Slovenian transmission and high voltage distribution, there were more than forty breakdowns on different transmission lines from 110 kV to 400 kV [1], [2].

In February 2014 a large part of Slovenia suffered a catastrophic demolition on the low and medium voltage distribution network, on 110 kV distribution and transmission lines, and on the 220 kV and 400 kV transmission lines. Especially disastrous were the consequences on the line between the transformers in the vicinity of Ljubljana and Divača, where 220 kV and 400 kV transmission lines were destroyed. The additional load of the ice also broke the towers and tore the wires [1], [2].

During the period January 30th to February 7th, 2014 a large area of Slovenia (essentially everywhere other than the lower parts of Primorska region, Vipavska Valley, Brkini and parts of Prekmurje) was hit by a natural disaster in the form of freezing rain. Freezing rain is a drizzle that falls onto a sub-zero surface, and consequently freezes, and can lead to significant mechanical loading [1], [2].

The 2014 freezing rain storm was exceptional because it affected a large part of Slovenia, part of south Austria and west Croatia (Gorski kotar), and caused considerable damage to forests, roads, rail and electrical infrastructure [1], [2].

Geographically, the Republic of Slovenia occupies a small, yet meteorologically diverse area. At this junction of Alpine, Carpathian, continental and Mediterranean climate, the weather can vary significantly over small distances. The mixing of different climates is often the consequence of simultaneous weather systems and terrain, which can cause extreme weather conditions. The consequences of these on both natural and urban environments are classified as disasters. For several years, climatologists have warned that natural disasters are consequences of global warming, with an impact on everyday life [1], [2].

Slovenian statistics of damage caused by freezing rain and glaze ice is unfortunately full of events with significant consequences on the distribution network, including failure of cross-arms, entire towers and entire sections of overhead line (OHL) routes [1], [2].

The ice storm of February 2014 paralysed Slovenia, with damage to overhead lines of all voltages, including voltage (LV), medium voltage (MV) and high voltage (HV). The consequences were catastrophic, and more than 250,000 people were left without electricity for several days. Whole cities were without electricity. After a few days of complete darkness, aggregates were turned on, and the restoration of LV and MV lines as well as some 110 kV OHLs started, with the help of emergency restoration towers [1], [2].

Fig. 1 Glaze ice on a conductor on the OHL 110 kV Cerkno – Idrija [1].

Around midday Friday, January 31st, the snow turned to rain in most parts of Slovenia. It was snowing in the north-western part of the country. On Saturday, February 1st, the weather conditions worsened in most parts of Slovenia, where the temperatures were around -3°C. Slovenia was covered in ice. At around 5.30 p.m., the OHL 220 kV Kleče–Divača failed, and an hour later the so did the OHL 400 kV Beričevo–Divača (Fig. 2) [1].

Fig. 2 Typical image of a 400 kV OHL tower [1].

Severe freezing rain in the district of Elektro Ljubljana resulted in the most severe damage to the area between Vrhnika and Logatec.

During February 2nd, the OHL 110 kV Kleče–Logatec between towers 92 and 102, as well as the OHL 110 kV Vrhnika–Logatec between towers 84 and 94 and the OHL 20 kV Vrhnika–Logatec between towers 8 and 19, were completely destroyed (Fig. 3 and 4) [2]. The technical brochures CIGRE are of great help with the development of the application for determining ice formation on conductors [6]–[9].

Fig. 3 Disastrous damages on OHL 110 kV Kleče– Logatec [2].

Fig. 4 Disastrous damages on OHL 110 kV Kleče– Logatec [2].

III. BME'S ICE PREDICTION MODEL

Besides the geometry of the conductor, local environmental conditions, such as rainfall, ambient temperature, humidity, wind speed and direction, also play an important role in the formation of an ice layer on the surface of the conductors. These parameters determine the structural properties of the resulting ice layer and thus its properties.

Based on these environmental factors, three types of ice can be distinguished, which can cause the high mechanical load to the conductors through high-adhesion and density. These three ice types are wet snow, glaze and hard rime.

BME's ice type determining system is established to predict the expected ice type based on environmental parameters, on which based the ice layer diameter and extent of extra mechanical load can be calculated according to the actual ice type. The algorithm takes into account the ambient temperature, precipitation type and intensity, relative humidity and also the temperature of the conductors in order to determine the expected ice type. The results of the system can be the following: wet snow, a mixture of wet snow and glaze, glaze, a mixture of glaze and hard rime, hard rime or ice formation is not expected. Ice can only shape when conductor temperature below 2 °C, but due to the uncertainty of the conductor temperature calculation model and the deviation of line monitoring devices, this threshold value was set to 3 °C in the model, which appears as a safety factor while it can also increase the number of false alarms [13].

The structure of the ice layer deposited on the overhead line conductors largely depends on the type of precipitation, which through several parameters - water droplet/snowflake velocity and mass concentration, collision efficiency, adhesion factor, deposition factor - influence the forming ice layer. In this way, the ice layer will be accreted differently for different types of ice, so the calculation of the thickness of the resulting ice sleeve and the consideration of the extra mechanical load caused by it should be calculated in different ways depending on the type of ice.

BME's ice determining system use Lacavalla et al. model [14], [15] for wet snow calculation, Pytlak et al. model [16 for glaze computation and Shao et al. model [17] for hard rime estimation.

IV. ICE DETECTION SYSTEM OF OTLM SMART

A. *Development of OTLM SMART line monitoring sensor*

The severe ice storm was observed in Slovenia in 2014, indicates the demand for new safety measures during overhead lines operations. For this purpose, one of the additional safety precautions was to inspect the overhead lines when received information from national weather service that ice storm is possible in the given region. Based on this forecast information the TSO should check if ice storm is affected by the overhead line or not. Unfortunately, some overhead lines are located high in the hills and approach is nearly impossible in case of snowy winter time.

These facts encourage the manufacturer to build a camera into OTLM SMART line monitoring sensor (Fig. 5), which can be used for monitoring overhead lines and to check the ice status on overhead line conductors.

Fig. 5 Installation of OTLM SMART on the conductor.

B. *OTLM SMART's ice detection function*

The thermal monitoring of OHL in a transmission grid is possible with various technologies on different power levels. The choice depends on the requests given by the transmission system operators. The sag and the conductor temperature are two key parameters which define the ampacity of the OHL. The conductor temperature is defined by thermodynamic equilibrium where the heat input equals heat losses. The conductor is heated by the solar radiation and by the heating effect of flowing current (I^2R).

At the time of development and understanding thermal rating calculations of overhead lines we used excellent literature CIGRE [18]–[23].

Equation (1) shows the relationship between heating and cooling [23]:

$$P_J + P_M + P_S + P_i = P_C + P_r + P_w \tag{1}$$

P_J - the Joule heating
P_M - the magnetic heating
P_S - the solar heating
P_i - the corona heating
P_C - the convective cooling
P_r - the radiative cooling
P_w - the evaporative cooling

The conductor temperature can be measured in one spot or continuously all over the length of the line. The spot method is cheaper but the device has to be carefully placed on the OHL. It should be mounted on the bottom conductor, on the part of the line which passes through the area where the landscape changes sharply and a line is shielded from the wind by various natural or manmade barriers. In complex terrain, the number of measurement points should be greater than in flat woodless areas.

The ampacity was calculated by using the newest CIGRE formula (TB 601) [23]. Considering conductor temperature and ambient weather conditions the real-time sag and safety height are calculated by using a mathematical model [23].

A mathematical model has been developed for sag and horizontal force calculation. The model was developed as a computer application. The model includes installation conditions and conductor characteristics and determines the interdependence between conductor sag and horizontal force for actual conductor temperatures. The computer application is an integral part of OTLM SMART software.

The developed mathematical model includes mechanical and physical characteristics of the conductor, conductor weight and sag size for the calculation of internal forces.

Combining measurements of conductor geometry and sag at several conductor temperatures with software is using for calibration of the sag and angle function. Ensuring conformity is crucial for the implementation of the function ICE-ALARM since a continued growth of discrepancy between the measured and calculated angle in ambient conditions is a sign of glaze ice on the conductor.

The paper presents the concept of the application and the relation between the geometry and load parameters on the catenary curve when ice or heavy snow builds up and the estimated effect of the current increase on the melting of ice as a tool for the prevention of tower collapse.

A conductor is a quasi-statically loaded self-supporting element, where a tensile force changes depending on the oscillating temperatures and mechanical loading. Due to the complex design of the conductor, it is necessary to determine the behaviour of the conductor during the cyclic tensile loading and the stable elastic constant, which is applied to determine a change in the force depending on the elongation.

The parameters of the catenary curve at the temperature of the freezing rain represent the initial state of the activation of the ICE-ALARM computer algorithm. If favourable conditions for the formation of ice appear during the continuous monitoring of the conductor condition and condition on the route in the surroundings of the meteorological station then it is possible to estimate the amount of additional loading and the ice thickness on the basis of the change in the angle of inclination and by knowing the tension-deformation behaviour of the conductor at increased loading.

Fig. 6 shows the change in the angle in accordance with the model and the angle measured by the inclinometer. White circles present actual average angles as a function of average temperature of conductor measured in the time interval of 30 s. Red circles present the expected behaviour of the conductor and/or a change in the angle due to the build-up of the ice on the conductor.

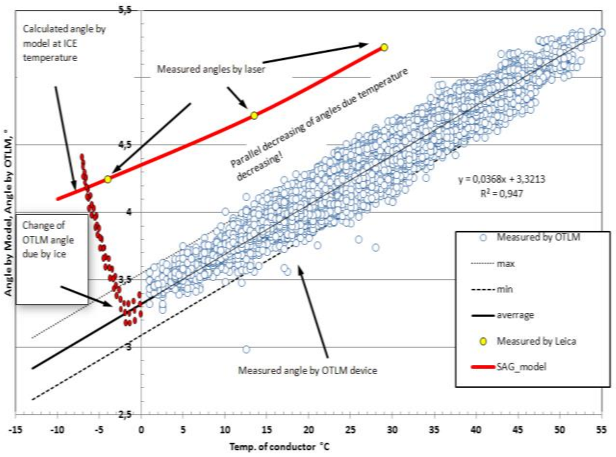

Fig. 6 Change in an angle at the OTLM SMART device position depending on temperature.

The continuous red line in Fig. 6 represents the angle of inclination depending on temperature according to the mathematical model. If an angle significantly increases in the meteorologically favourable ice conditions and the temperature inversion and if the calculated angle significantly differs from the angle measured by inclinometer, the application informs the operator that ice has built upon the conductor.

Fig. 7 shows the expected change in the angle at the position of the OTLM SMART device according to the model and the angle measured through the time interval during the detection of ice build-up on the conductor. The reliability of the ice build-up measurement depends on the accuracy of angle measurement of +/- 0,25° and causes a time lag during the beginning of ice build-up and the beginning of the ICE-ALARM activation. The application is activated only after the measured change in the angle of inclination is larger than the statistical error of angle measurement.

ICE-ALARM warns the operator that an increase in the current is required. The larger current gradually increases the temperature of the conductor, but the ice can still build up, elongating the conductor and consequently increasing the angle of inclination. Based on the characteristic of the elastic and constant elongation of the ACSR 240/40 conductor recorded in the laboratory, it is possible to determine and monitor the elongation.

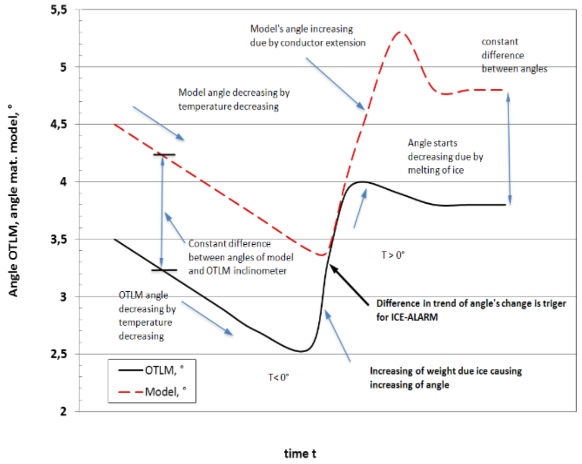

Fig. 7 Change in an angle of inclination during the activation of ICE-ALARM and melting of ice.

The model (red hatched line in Fig. 7) monitors the elongation of the conductor and re-calculates the change in the angle, accordingly. At the moment, when the ice thickness begins to decrease (the highest value on the continuous line in Fig. 7), the angle measured by the inclinometer in the OTLM SMART device also starts reducing. When all of the ice has melted, a new geometry of the catenary curve and/or a new sag of the conductor and new initial position before the new build-up of the ice are obtained, as it has been simulated by a laboratory testing of the conductor.

Fig. 8 shows an increase in the force during the ice build-up depending on the g factor and the angle on the location of the OTLM SMART device. The initial value of the force equals the initial tensile strain in Fig. 15, and amounts to 15,25 kN on one side and to 15,24 kN on the other one, at the initial angle of 4,25° at the position of the OTLM SMART device. The increase is possible only up to critical fracture strength of the tensile force of the conductor, which amounts to 86,4 kN. In case of the presented span, it corresponds to the gravity factor of 9,2 g and an increase in the angle by 4,56° and/or to 8,24°, as shown in Fig. 8.

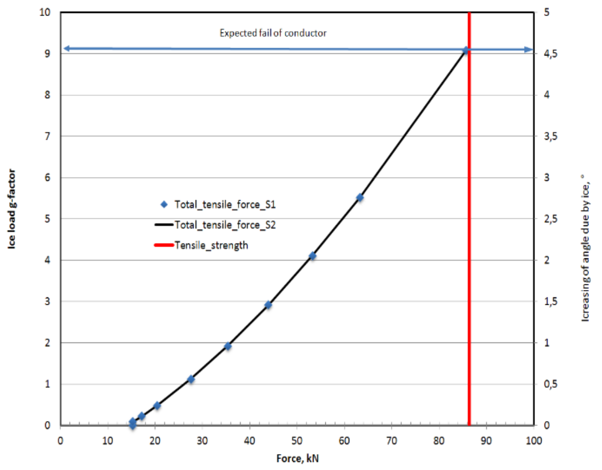

Fig. 8 The relation between force, g factor and the angle of inclination at the location of the OTLM SMART device.

Fig. 9 presents the relations between the total angle of inclination, additional tensile strain in the conductor and ice thickness. The angle to ice thickness dependence is linear, as evident in Fig. 9, while the increase in horizontal (shear) strength up to the destructive force of 86,4 kN is exponential.

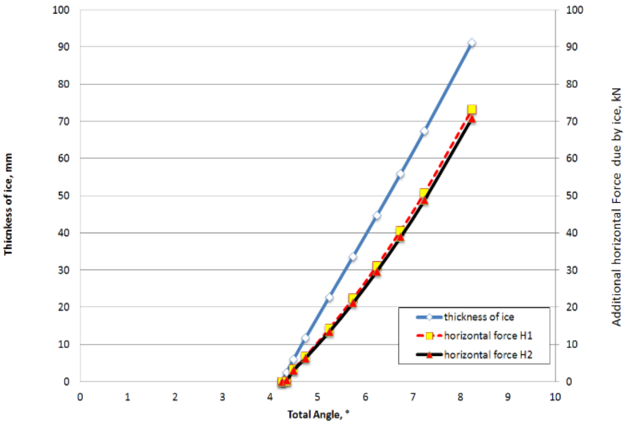

Fig. 9 The relation between ice thickness, the angle of inclination and horizontal forces.

In order to calculate the current necessary to remove the ice build-up, Joule heating, solar radiation, radiation of the conductor surface, convective heat transfer and melting of water have to be taken into account.

Since Joule heating represents the dominant mechanism, convection and radiation shall be neglected in further calculations. Specific thermal capacity (c_{Fe}, c_{Al}, c_i) has to be considered for each separate material.

The heat needed to heat the conductor and ice build-up from – 5 °C to 0 °C and the transformation of ice into liquid water is obtained by calculating the mass of the steel core, conductor, Al-stripes and ice per 1 m length of conductor:

$$\frac{Q}{l} = A_{Fe}\cdot\rho_{Fe}\cdot c_{Fe}\cdot\Delta T + A_{Al}\cdot\rho_{Al}\cdot c_{Al}\cdot\Delta T + \rho_i\cdot\pi((r+\delta_i)^2 - r^2)\cdot(q_i + c_i\cdot\Delta T) \tag{2}$$

The heat of conductor per 1m length is in balance with specific electric resistance per 1m length, and therefore can be written as:

$$\frac{Q}{l} = \frac{R}{l}\cdot I^2\cdot t \tag{3}$$

Eq. (3) by rearranging gives required current, by considering specific heat and specific electric resistance in given time of heating:

$$I^2 = \frac{(Q/l)}{(R/l)\cdot t} \tag{4}$$

The required current I also can be written by the following equation:

$$I = \sqrt{\frac{1}{t\cdot R}\left[A_{Fe}\cdot\rho_{Fe}\cdot c_{Fe}\cdot\Delta T + A_{Al}\cdot\rho_{Al}\cdot c_{Al}\cdot\Delta T + \rho_i\cdot\pi((r+\delta_i)^2 - r^2)\cdot(q_i + c_i\cdot\Delta T)\right]} \tag{5}$$

(R/l) – the specific resistance of conductor in [Ω/m]
c_{Fe} – the specific thermal capacity of steel [J/(K·kg)]
c_{Al} – the specific thermal capacity of aluminium [J/(K·kg)]
c_i – the specific thermal capacity of ice [J/(K·kg)]
□$_{Fe}$ – specific mass density of steel [kg/m^3]
□$_{Al}$ – specific mass density of aluminium [kg/m^3]
□$_i$ – specific mass density of ice [kg/m^3]
q_i – specific mealting heat of ice [J/kg]
□$_i$ – thickness of ice [m]
A_{Fe} – surface section of steel [m^2]
A_{Al} – surface section of aluminium [m^2]
□T – conductor temperature below zero [K]
t – time [s]

To obtain the equation (2) we also neglected the temperature dependence of metal resistivity and electrical conductivity of the ice. The current as a function of ice melting time for various thicknesses of ice on the Al/Fe (ACSR) 240/40 conductor observed is calculated from the equation (2), as shown in Fig. 9.

Under the assumption that the ice build-up stopped at the time of a current increase, the time needed for ice melting can be graphically read from Fig. 10.

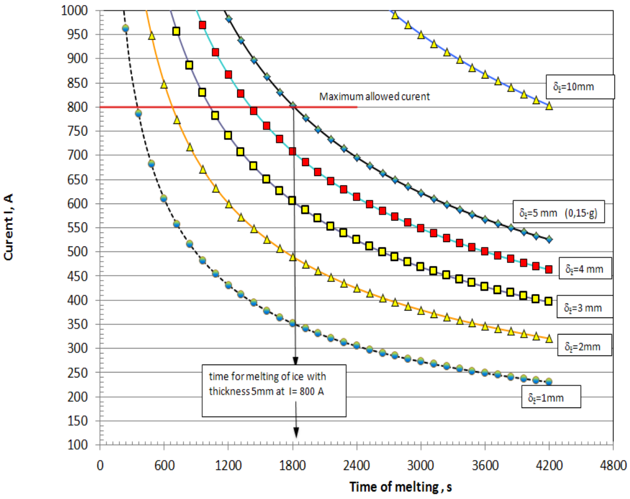

Fig. 10 Speed of ice melting depending on ice thickness and current.

A red line presents the result for the maximum current that is allowed by the HV equipment in the overhead power field (e.g. disconnector, break-switch, measuring transformers), i.e. 800 A. This line presents the shortest possible time for the elimination of the ice from the conductor by an increase in the current. In case of strong precipitation, when the quantity of freezing rain on the conductor is larger than the quantity of melted ice, the additional loading only increases and leads to the tearing of the conductor at a force of 86,4 kN and at an angle of incidence on the position of the OTLM SMART device at 8,24°.

V. TWO-LEVEL ICING MODEL

Based on BME’s ice prediction model and OTLM SMART’s ice detection function a two-level model was established and under implementation for OHL 110 kV Kleče-Logatec. In this way, the ice accretion can be predicted based on weather forecast according to BME’s ice type determining system co-operated with national weather service (ARSO). The accreting ice layer can pose a threat if the sleeve radius exceeds 10 mm or if the extra mechanical load caused by it exceeds 1 kg/m during the icing event. Therefore, the threshold values for ice alarm settled to be according to these limitations.

Furthermore, if ice alarm was sent to the system operators, they can monitor the real field conditions of the conductors with OTLM SMART device, which can not only measure the inclination of the monitored span, but also the conductor's state can be observed with the built-in camera. Therefore, the ice prediction model’s results can be compared with the actual conditions, and the required intervention can be determined according to the growth rate of the ice layer.

A severe ice storm in Slovenia (back in 2014), defined new safety measures of overhead lines operations. One of the additional safety precautions was to check the overhead lines when received information that ice storm is possible in some region. When received such information, then TSOs and DSOs can check is ice storm in present or not. Unfortunately, some overhead lines are high in the hills and with high snow during the winter assess is nearly impossible. Mentioned facts encourage producer of OTLM SMART to build in a camera which can be used for monitoring of overhead lines and to check the ice status on overhead lines. Besides the presence of the ice, the operator can check what kind of ice is present - glaze ice, wet snow, etc. In case the operator is able to heat the conductor, then the critical point is the tower. So, a camera was turned towards the tower to check the conductor and the tower at the same time. This feature enables the operator to check the status of an overhead line without the presence of maintenance personnel and act accordingly on the actual status and not on mathematical or prediction bases.

VI. CASE STUDIES

To illustrate the operation of the two-level icing model, case studies are presented here. Although there was a “green winter”, which means there was no considerable icing, only some snowing events occurred, nevertheless the operation of the model can be showed through these snowing events.

Fig. 11 Tower No 95 (2x OTLM SMART and 1x wether station).

Case studies were made for OHL 110 kV Kleče -Logatec single circuit transmission line equipped with ACSR 240/40 mm^2 conductors. On OHL there was installed on tower No 95 and No 98 on every tower two OTLM SMART and one weather station (Fig. 11).

A. Case study 20 November 2018

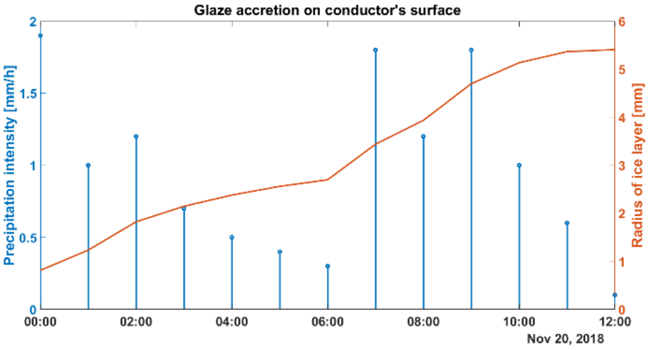

Fig. 12 Glaze accretion according to BME’s model.

BME’s model predicted wet snow and glaze ice types based on the weather forecast for different grid points. The expected ice thickness was 5 to 6 mm for glaze and 10 to 14 mm for wet snow. Fig. 12 shows the accretion of glaze ice depending on precipitation intensity.

On the other hand, as Fig. 13 shows the image captured by OTLM SMART device, there is a slight ice layer can be seen on the bottom of the wire.

Fig. 13 Real state of a phase conductor.

B. Case study *18 January 2019*

A mixed type of ice from wet snow and glaze was anticipated according to BME’s ice prediction model with a thickness between 9 to 12 mm for the different forecast grid points. The expected ice formation is shown in Fig. 14.

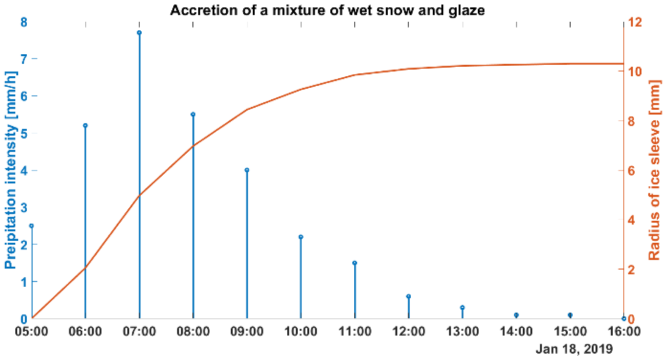

Fig. 14 Glaze accretion according to BME’s model.

The real field conditions are shown in Fig. 15, where a huge snow deposit can be seen in the front of the camera, and a layer of ice on the tower.

Fig. 15 Real state of a phase conductor.

VII. TEXT FONT OF ENTIRE DOCUMENT

The operation of the model was investigated between the 2018-19 winter time, when only slight ice formed on the conductors mostly form wet snow. BME's ice prediction model forecasted properly the ice formation, while the quantitative estimation should be fine-tuned when significant ice sleeves will occur. On the other hand, OTLM SMART device offers an appropriate solution for real-time monitoring of the conductors, which can be the basis to the intervention for system operators.

VIII. CONCLUSIONS

According to FLEXITRANSTORE's project, this paper presented the development of a two-level ice prediction and detection model for high voltage overhead lines.

The first level is a weather-based system, which aims to predict the possibility of different ice types – wet snow, glaze, hard rime – accretion on conductors. The model is able to calculate the radius of the ice sleeve and its mechanical extra load based on the accreting ice layer's type.

On the second level, a computer algorithm was developed for re-calculation of the sag and tensile strains in the conductor. It takes into account the actually measured form of the catenary curve of the conductor on the presented span at the conductor temperature measured by OTLM SMART. Based on the knowledge about the change in the sag of the catenary curve and the tensile forces dependence on the temperature of the conductor and monitored weather conditions, it is possible to determine the moment of activation the ICE-ALARM application. Furthermore, OTLM SMART sensor is able to monitor the actual state of the conductors with its camera.

The development of the ICE-ALARM application is based on the existing computer algorithm in the OTLM SMART device. The developed computer algorithm is based on the mathematical model for a re-calculation of the sag and tensile strains in the conductor. It takes into account the actually measured form of the catenary curve of the conductor on the presented span at the conductor temperature measured by OTLM SMART as the initial state. Based on the knowledge about the change in the sag of the catenary curve and the tensile forces dependence on the temperature of the conductor and monitored weather conditions, it is possible to determine the moment of activation the ICE-ALARM application.

When ICE-ALARM is started, the required current for ice elimination is calculated. The current needed for heating the conductor and melting the known thickness of ice depends on the temperature difference $\square T$ and heating time t. The maximum thickness of ice at which the conductor fails is also determined. The angle on the position of the OTLM SMART device under the maximum thickness of ice is determined by the algorithm developed in this paper. The loading interval span is given and the prevention of damage caused by the accumulation of ice or wet snow can be influenced by the current load.

The essence of the two-level system is the prediction opportunity combined with the real-time monitoring function. System operators get a forecast of the seriousness of the icing event in this way, while the intervention can be made according to the danger factor, therefore the number of unnecessary interventions can be reduced.

ACKNOWLEDGMENT

This work has been being developed in the High Voltage Laboratory of Budapest University of Technology and Economics within the boundaries of FLEXITRANSTORE project, which is an international project. FLEXITRANSTORE (An Integrated Platform for Increased FLEXIbility in smart TRANSmission grids with STORage Entities and large penetration of Renewable Energy Sources) aims to contribute to the evolution towards a pan-European transmission network with high flexibility and high interconnection levels.

The authors would like to acknowledge ARRS (Slovenian Research Agency) for the support provided during this research in the frame of the P2-0137 research program.

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European Commission | Horizon 2020 European Union funding for Research & Innovation

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