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Icing Forecasting on Overhead Lines and Development of Early Warning System, a Real Case Study in Turkey

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SUMMARY

Overhead line conductors are one of the fundamental parts of both transmission and distribution systems. An event that would damage to the overhead line conductors leads to energy interruptions and blackouts on wide area of supply which results with labour and financial losses. In order to operate electrical systems efficiently and ensure energy continuity, faults on overhead lines should be minimized.

Due to weather conditions in winter season, fault risk increases for overhead lines. One of the most substantial problems experienced during winter season on overhead lines is accumulation of ice on the lines. Together with faults due to ice load, due to the challenging nature of winter season and geographical conditions, re-energizing takes a long time. Not like other electrical faults, the ice load on overhead lines occurs due to atmospheric and climatic conditions. For this reason, it is possible to predict ice loads and prevent it before it causes faults in electric networks. There are certain factors to estimate occurrence of ice load on overhead lines. Only meteorological data is taken into account while evaluating the icing conditions of the overhead lines in the literature. To evaluate icing conditions on overhead lines, not only meteorological data but also loading conditions of overhead line should be considered. In studies to anticipate the icing on the overhead lines, in addition to parameters such as characteristic values of overhead lines, current value that flows on overhead line and environmental conditions also should be taken into consideration. As well as temperature, wind speed, solar radiation and humidity, also the conductor diameter, and conductor resistance parameters should be used to determine icing risk on overhead line. In large power systems, it is a difficult task to remove ice from long lines. To overcome this challenge, significant levels of successful technologies have been developed. These methods mainly focuses on anti-icing technologies such as breaking ice on overhead lines with blades or vibration. Also coating technologies applied in literature to prevent ice deposit on overhead lines. Although positive results have been obtained from these effective technological applications, it is not appropriate to use it widely in large power systems in terms of efficiency.

In this study, meteorological forecast and weather station data used for developing icing forecast and warning

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system for a real system in Turkey. The developed system can calculate the current values required to prevent icing on the overhead lines while taking into account the environmental and operating conditions as well as the ice forecast. In this study, 9 days forward forecast data with 95% accuracy were used within 1 km2 area. Hourly basis ice predicting was carried out using real-time weather forecast and line loading data. Required current values are calculated to prevent icing on overhead line. To increase the accuracy of calculations and check meteorological forecast data, a weather station was established. The developed ice forecast and warning system has been implemented in a real system and shown successful results in icing forecast on overhead lines to warn operators before fault occurs. The developed system has contributed to prevention of the ice load problems encountered on the transmission and distribution networks.

KEYWORDS

Ice Load Prevention, Overhead Lines, Early Warning System.

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1. INTRODUCTION

One of the core principles of power systems is continuity of energy supply in network. For the continuity of electricity supplied to the consumers, the elements used in the network must be operated properly. For this reason, if a fault occurs in the system, the fault should be removed and system should be recovered as soon as possible.

The fact that overhead lines are open to external influences makes it difficult to provide healthy operating conditions especially in winter months. One of the most important problems experienced during the winter months in the overhead line networks is the accumulation of ice load on the overhead lines. This leads to serious effects leading to long interruptions. Due to climatic conditions and geographical conditions, these problems can take a long time to be solved and consumers can stay without electricity for a long time. In order to prevent icing on overhead lines, the formation of water and snow droplets on the surface of the conductor must first be investigated.

There are certain factors in the overhead lines affecting the occurrence of icing and the emergence of ice loads. In [3], it states that the icing occurs between +2ºC and -3ºC on transmission lines. With events such as rain, fog and snow, air temperatures drop and the water droplets on the conductor surface become icing. In [4], the conditions of icing in Quebec (Canada) were examined especially in March and November for years. With the test system established in Quebec, it is observed that icing on the surface of the conductor occurs between -8°C and -0.5°C. Especially at -2°C. In [5], it was observed that in Italy, especially in areas where terrain conditions are rough, icing occurred on transmission lines when the air temperature was between -0.5°C and 2°C with snowfall. In [6], it states that icing occurs most when temperature is between +2°C and -8°C. At -10°C, there is no icing because the amount of moisture is too low. In [7], in case of snowfall in France, icing events in temperature range of +2.5°C to 0°C were examined considering geographical structure and the height of the lines, and it was seen that icing occurred. In [8], it has been observed with monitoring system that the icing events occur in the winter season when the temperature is between 0°C and -8°C and the wind speed is between 0 and 5 m/sec. The factors affecting the occurrence of icing and ice load on overhead lines are as follows:

Humidity; For the formation of ice, relative humidity should be more than 90%. Humidity rate decreases with the temperature drop.

Temperature; The icing phenomenon is closely related to the temperature value. Icing occurs mostly between +2°C and -8°C. But, if it gets too cold (< -8°C), icing won't occur. Also, type and intensity of precipitation affects the formation of ice.

Wind; The wind makes water particles in fog accumulate on the conductor surface. With higher speed of wind, more water droplets can touch the conductor's surface and the ice load increases. Wind direction also affects icing.

Solar radiation; It affects the heating of the conductor depending on the day of year, hour of the day, altitude and longitude. The solar radiation value hits the maximum especially in summer and takes the minimum values at nights and foggy weather conditions in winter.

Topography; The topography and the altitude affects the icing. The most important thing is where lines pass through the land with wind blows slower.

2. SYSTEM STRUCTURE

Ice forecasting and warning system on overhead lines consists of two subsystems. The first one is the meteorological station. Meteorological observation station; is a system structure in which climatic conditions can be monitored instantaneously. Meteorological data are measured and recorded through the sensors in the structure. The meteorological observation station alone is not sufficient to estimate icing on overhead lines. Because of the technical limitations, it is not possible to establish an observation station at every point along the line route where icing events may occur. For this reason, meteorological forecasting data are needed as well as data from the meteorological observation station.

It is extremely important to determine the resolution of data and the number of days ahead for the meteorological forecast. This sensitivity affects the prediction of ice at a significant level. In this study, 9 day forward forecast data was used with %95 accuracy within 1 km2 area. A meteorological observation station was established to increase the accuracy of icing and meteorological forecasting data. The data from the meteorological observation station and the data received with meteorological forecast were compared. It is seen that the data are very similar. Thus, the accuracy of the recorded data at the meteorological observation station was confirmed.

2.1. HARDWARE INFRASTRUCTURE

The hardware infrastructure of the ice forecasting and warning system constitutes the equipment of the meteorological observation station. The instantaneous data from these instruments can be seen instantly with the developed interface. The meteorological observation station has sensors to measure temperature, humidity, wind direction, wind speed, pressure and solar radiation. The hardware infrastructure of the ice forecasting and warning system is as given in Figure 1.

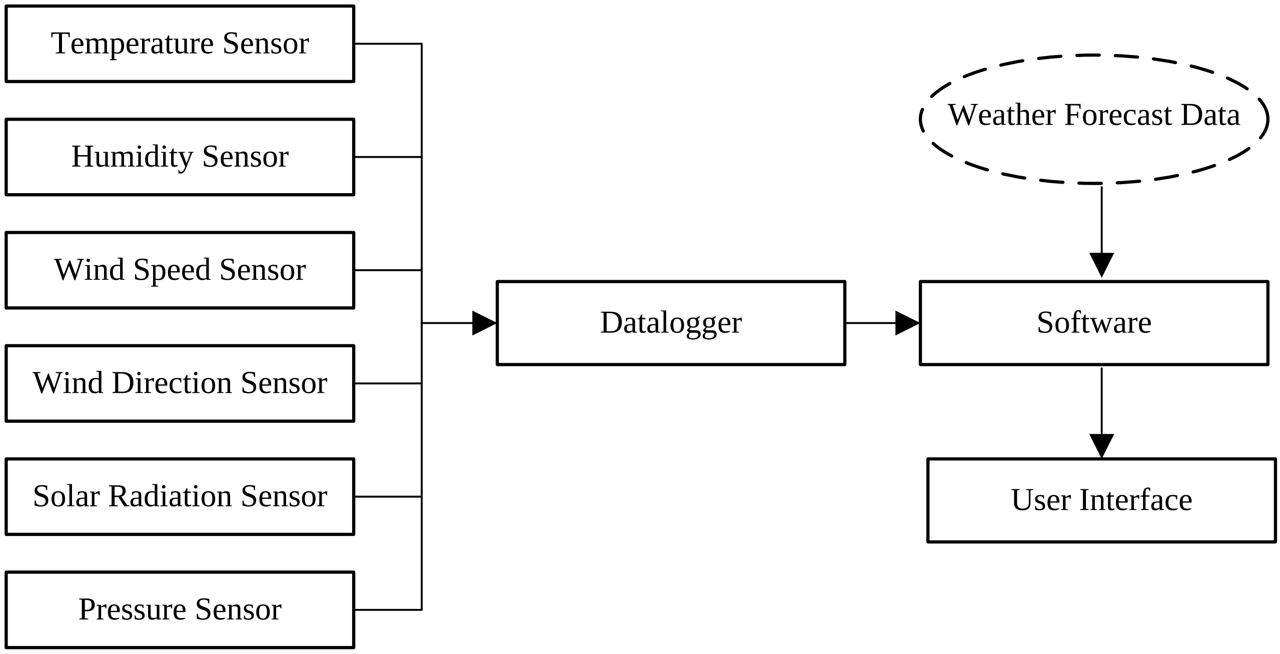

Figure 1 Hardware Infrastructure

The sensors and positioning of the weather station are given in Figure 2.

Figure 2 Meteorological Station

Environmental factors play an important role as well as current flow as a design criteria of overhead lines. Conductor's surface temperature should be taken into consideration when predicting and preventing icing on overhead lines.

Depending on the meteorological data, thermal equations given in IEEE Std. 738 can be used to form an opinion about thermal condition of line [2]. The IEEE standard is based on a consideration of various methods and provides equations for calculating the current–temperature relationship of overhead line. Many factors affecting the conductor surface temperature on overhead lines. Main factors for cooling is convection heat loss and radiation heat loss. And for heating is solar heat gain and joule heat gain [9].

Conductor surface temperature can be calculated by numeric methods taking into account current and weather conditions that vary with time on overhead lines. By considering the thermal limits of the studied conductor and the environmental factors, the current value required to prevent icing can be calculated. Depending on the meteorological prediction data, Equation 1 can be used to prevent the occurrence of icing on the overhead lines [2].

$$Q_C + Q_R = Q_S + I^2 R_{T_A} \tag{1}$$

Here;

Q_c: Convection heat loss,

Q_s: Solar heat gain,

Q_r: Radiated heat loss,

With Equation 1, Equation 2 can be obtained.

$$I = \sqrt{\frac{Q_C + Q_R - Q_S}{R_{T_A}}} \quad (2)$$

Here;

I: Current value on overhead line,

R_{Ta}: Resistance at ambient temperature,

Q_c: Convection heat loss. With the warming of the cold air surrounding the conductor, the air rises and instead it changes with cool air. The loss value in this case is defined as convection heat loss. Equations for convection heat loss are given in Equation 3 and Equation 4.

If wind speed is lower than < 0.61 m/s;

$$Q_{C1} = K_a.[1.01 + 1.35.Re^{0.52}].k_f.(T_s - T_a) \quad (3)$$

If wind speed is higher than 0.61 m/s;

$$Q_{C2} = K_a.(0.754).Re^{0.6}.k_f.(T_s - T_a) \quad (4)$$

Here;

Re: Reynold number,

K_a: Wind direction factor,

T_s: Conductor surface temperature,

T_a: Ambient temperature,

$$Q_s = D.k_a.Q_{SH} \quad (5)$$

Here;

k_α:Absorption rate,

Q_{sh}: Standard solar emission,

D: Conductor diameter,

.

Q_r: Radiated heat loss. It characterized by losses due to electromagnetic waves due to temperature differences between objects and their surroundings.

$$Q_s = 17,8.D.E.[(\frac{T_s + 273}{100})^4 - (\frac{T_a + 273}{100})^4] \quad (6)$$

Here;

T_s: Conductor surface temperature,

T_a: Ambient temperature,

E: Stefan –Boltzmann factor.

Ambient temperature, weather condition and humidity are used for icing forecast. Temperature, wind parameters, conductor parameters and solar radiation are used to determine required current to prevent icing on overhead line. Figure 3 shows the algorithm which developed in order to prevent icing.

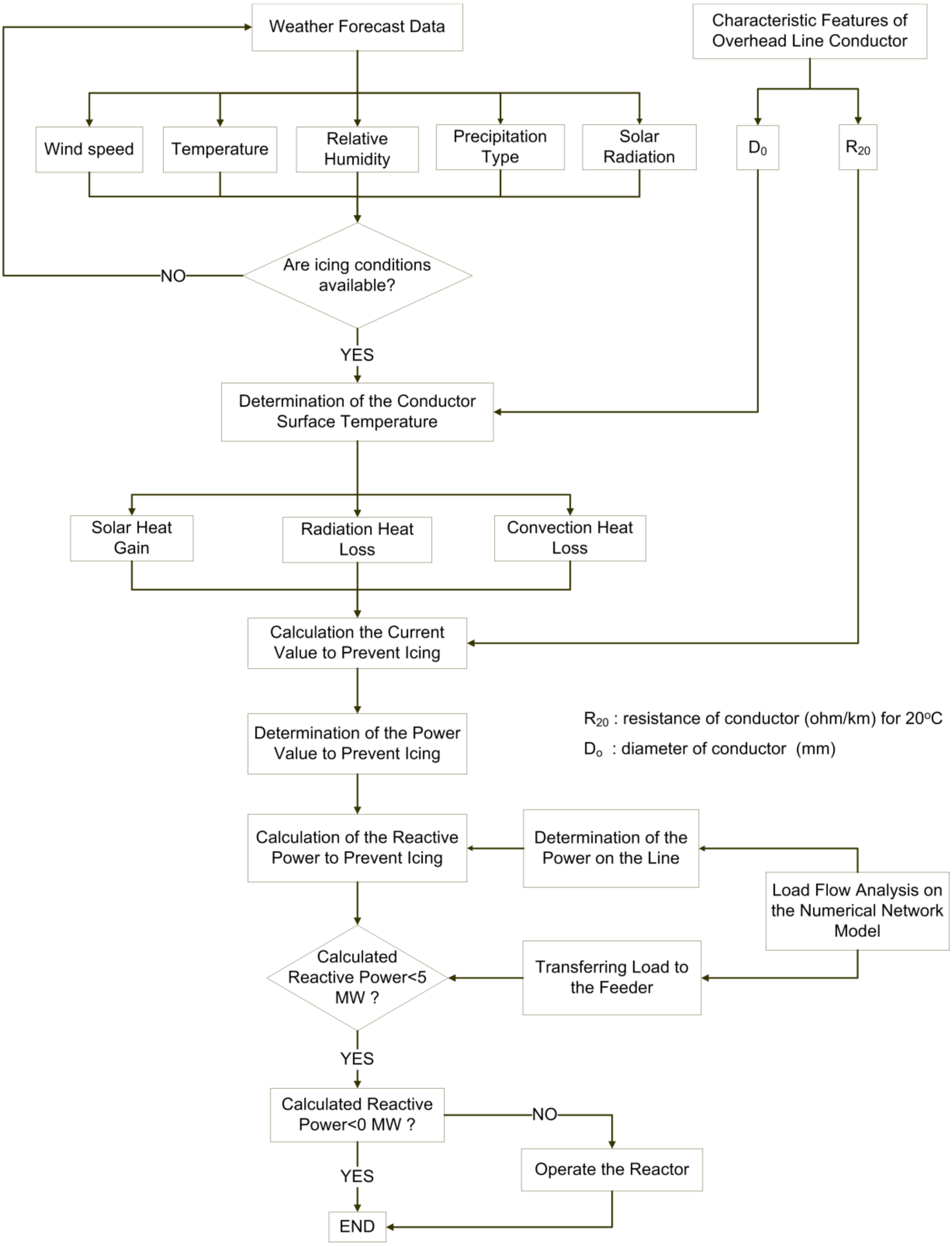

Figure 3 Developed Algorithm to Prevent Icing on Overhead Lines

In the developed algorithm, meteorological forecast data and conductor parameters are used to determine required current to prevent icing on overhead lines. For each calculation, icing does not occur if the current value is greater than the current required to prevent icing. If the current value is less than the current which required to prevent icing, icing occurs.

2.2 DESIGN OF WARNING SYSTEM AND WEB BASED INTERFACE

One of the important inputs of the algorithm to prevent ice accumulation on overhead lines is forecast data. This algorithm developed to fit power quality and monitoring system used by the DSO in Turkey. The power quality and monitoring system consists of connected sub-modules. The icing estimation and warning system is easily adopted by central system.

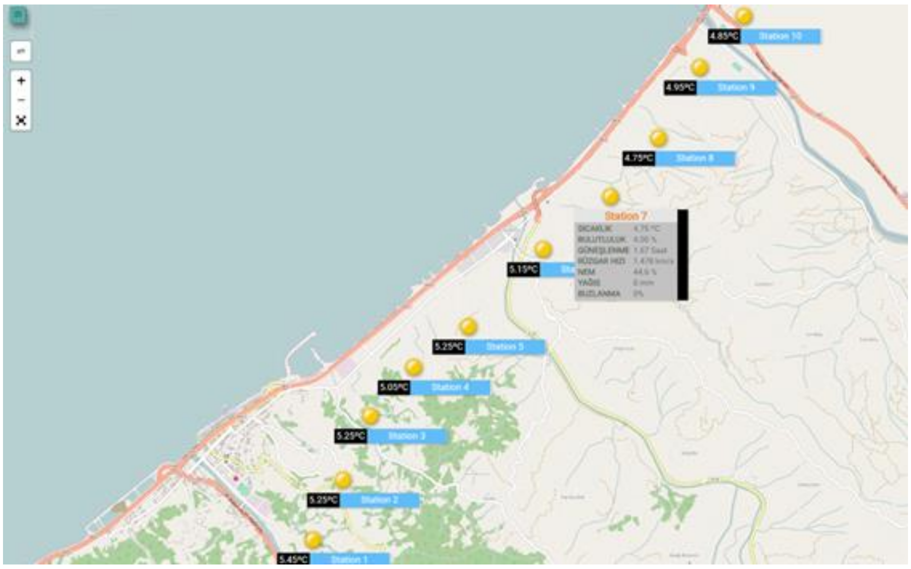

Figure 4 Weather Forecast Data on Web Based Interface

Weather forecast data was used for 10 different locations along the approximately 5 km line of icing. Estimated icing in the developed system is evaluated separately for 10 different locations.

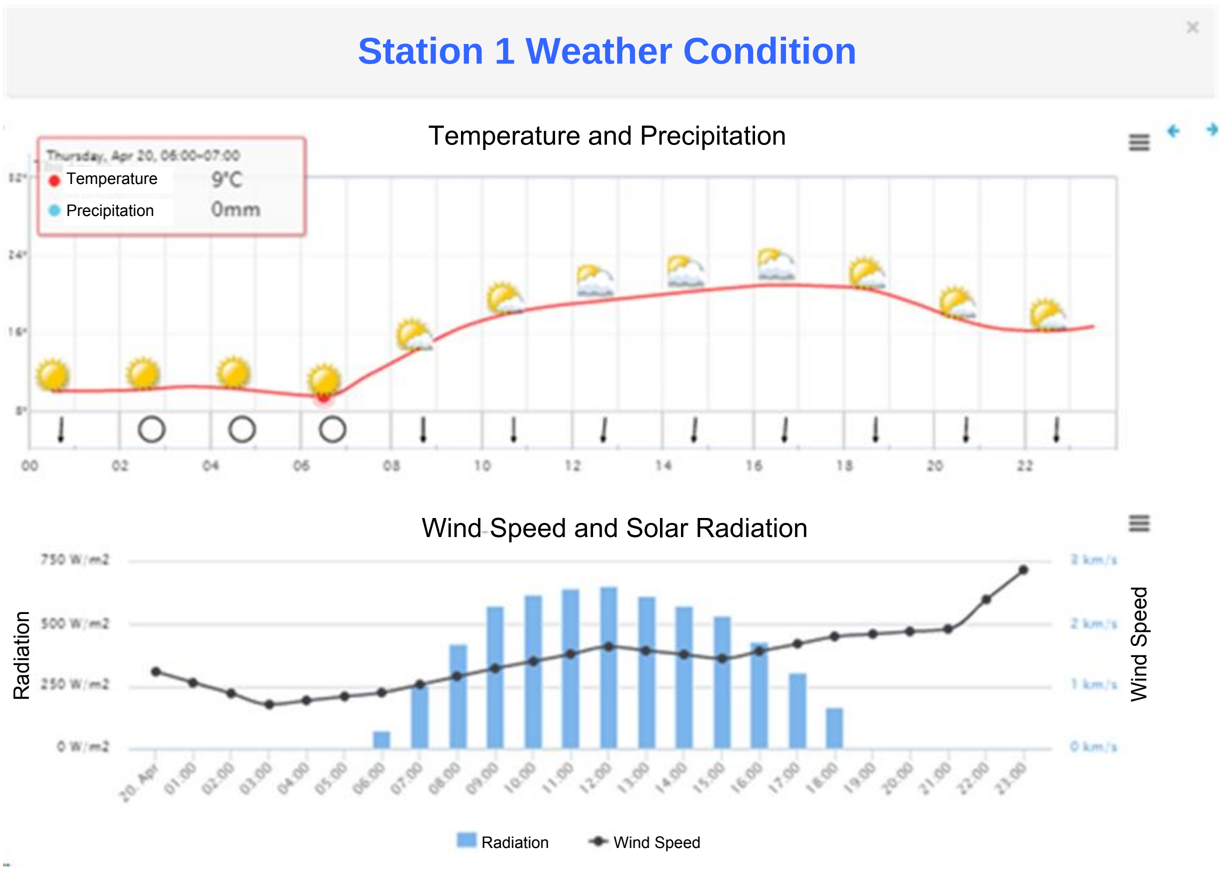

Figure 5 Trend Page on Web Based Interface

In order to evaluate icing risk on overhead lines and to see changes of risk percentage day by day, detailed view page is also prepared.

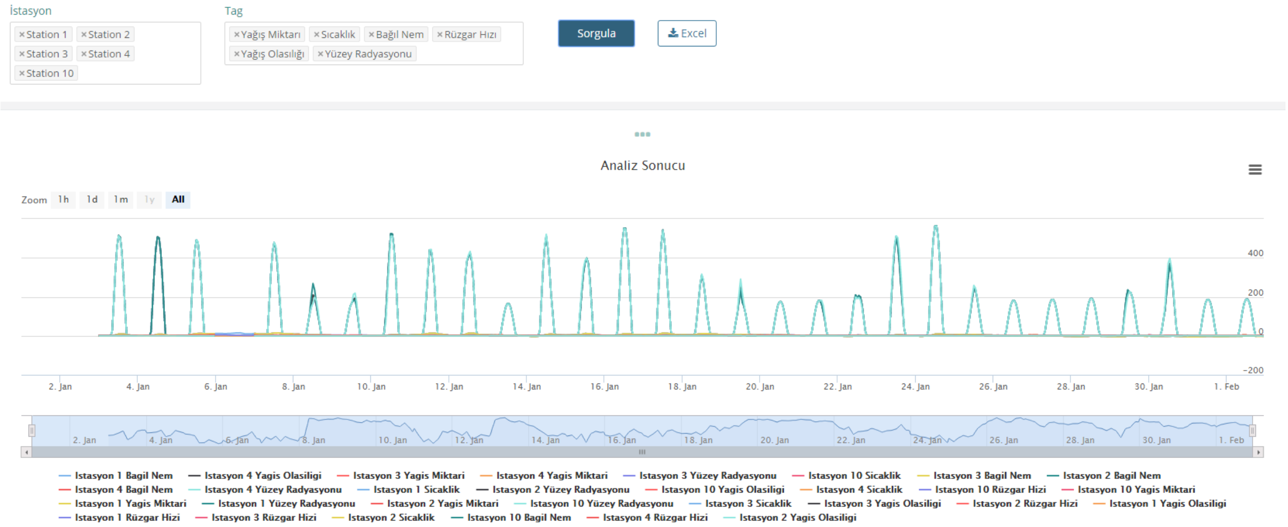

Figure 6 Icing Risk Evaluation in Detailed View Page on Web Based Interface

Icing forecasting with developed algorithm has been verified by real-time meteorological data. The overhead line which icing risk calculated and ice accumulation confirmed by field trip is shown in Figure 7.

Figure 7 Ice Accumulation on Overhead Line Confirmed with Field Trip

The developed algorithm calculates the current values required to prevent icing by taking forecast data and by confirm real time data with observation station. Taking meteorological forecasts is crucial to determine icing conditions. The algorithm first examines forecast data to determine if conditions for icing are occurring. With evaluation of meteorological data, icing risk and required current value to prevent icing could be calculated. This way, ice accumulation on overhead line could be prevented.

3. CONCLUSION

In this study, an algorithm and a web based interface was developed to determine icing on overhead lines and to prevent ice formation by examining the climatic and atmospheric conditions for the points where icing events might occur. In addition to the data from the meteorological observation station, meteorological forecast data has been integrated into the interface. With meteorological observation station and forecast data, the icing estimation was performed. The developed monitoring and evaluation system has been applied in a real distribution network and has been successful in ice prediction and warning the system operator.
The developed system with algorithm and interface can contribute to the prevention of the ice load problems on overhead lines that are encountered in the transmission and distribution networks. Forecasting ice accumulation on overhead lines is also important for operational planning. With developed system including

algorithm and interface, it is aimed to warn system operator about icing risk and prevent it to ensure energy continuity.

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