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OVERHEAD POWER-TRANSMISSION-LINE TEMPERATURE MAPPING BY ROBOTIC MEASUREMENT

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Abstract

Overheating of the power transmission lines can cause faults, leading to interruptions on the power distribution system. This temperature rise may cause more significant failures in the medium and long term. Symptoms of these faults occur early in the transmission line with small temperature increases or changes in current/voltage values. Current/voltage changes in very high-, high- and medium-voltage lines may not be detected in cases caused by uninterrupted failures. Electrical, insulation, and mechanical failures occurring in the power transmission line cause an increase in the temperature. Although the temperature change occurring on the line is generally neglected within the tolerance values, it may lead to significant failures and cause material and labour losses. In this study, the temperature of a power transmission line was measured by a line-inspection robot, transmitted to a remote control center, and time, location, and temperature changes were recorded along the line. The temperature profile of the line was created using these data and made it possible to predict any faults that may occur in the future. It helps to detect situations such as overload, environmental factors, and physical wear and take precautions. It is the first example in the literature where the temperature of the transmission line is measured and mapped instantly by a robot. In the experiment, an artificially heated part of the line is detected and shown in a temperature map.

Keywords: Line inspection robot, Line temperature, Power line inspection.

1. Introduction

The need for electricity and the fact that it can be used in every field make it indispensable. Although the electric power grid consists of many subsystems, transmission and distribution are the parts where malfunctions occur most [1]. Therefore, power transmission lines are the most important parts of the entire power transmission system. The quality, continuity and safety of the energy can be possible by tracking any changes on the line. There are many methods for detecting faults in power transmission lines. Omar et. al. [2] have classified faults in the transmission lines using LSTM networks. Power transmission lines are constantly affected by natural conditions such as rain, wind, lightning, sun, and unnatural conditions such as fires. They are vulnerable to bird attacks, landslides and floods as well [1, 3-5]. In addition to these effects, unbalanced load demands keep the energy transmission lines under constant pressure. Hence, the transmission lines must be kept under constant control and technical infrastructure must be improved continuously [6-8].

Nowadays, it is known that most of the failures in power transmission lines occur due to land conditions [9, 10]. Other malfunctions occur due to short circuits caused by birds or other natural effects, lightning, imbalances in load distribution and unknown reasons. The temperature of the transmission lines may increase as a result of these failures. It should be taken into account as the first sign of failure [11-14]. Although there are studies for determining the location of the fault in power transmission lines, it is much more important to take precautions beforehand. Studies have shown that the electrical and mechanical properties of the lines affect power loss, sagging, and conductor temperature during overloading of the power transmission lines [15-17]. It is therefore important to measure the temperature of the power transmission lines.

There are studies showing that conductor temperature gives more accurate results than current in safety analysis of power transmission lines. In the researches, models based on the conductor temperature of the line have been developed and data are collected from all the mounted temperature sensors and analyses are carried out [18-24]. Deformations caused by surface aging and natural effects in power transmission lines cause temperature increases with partial discharges.

Some external factors affecting the power transmission line temperature are shown in Fig. 1. Some factors increase the temperature of the line while others decrease it. Early detection of these phenomena is only possible with predictive maintenance models. This is possible by equipping the entire line with sensors at certain distances. However, this is both costly and requires a large workload [25, 26]. Different methods such as infrared thermography, thermal camera, overcurrent control relays are used for temperature analysis [27-30]. These faults also generate noise in the power line. Studies have shown that mechanical and electrical failures occurring on the line can be diagnosed accurately by 90% with temperature measurement [29, 30].

Temperature change may occur due to environmental factors or due to current difference in case of overload. Luo et al. [31] demonstrated the effect of temperature on the transmission line. They examined the line loss - temperature relationship with simulation on the New England IEEE39 bus system. Temperature of transmission lines depends on load current magnitude and conductor resistance. The DC resistance of a line is related to the conductive area, the conductivity of the material, the length and the line temperature. Since the number of layers in the conductor affects its heating properties, mechanical reinforcement is necessary.

The following Eq. (1) is used to calculate the current temperature for steel core conductors [32], where k_j is estimated parameter, R_{AC} is AC resistance at20 ^{o}C (Ω), α is temperature coefficient of resistance-per-degree (K^{-1}), I_{AC} is AC current (A). Solar heating equation is given in Eq. (2), where α is absorptivity, S is solar radiation ($\mathrm{W/m^2}$) D is conductor diameter (m).

$$P_j = k_j R_{AC} \left(1 + \alpha_t (T - 20)\right) I_{AC}^2 \tag{1}$$

$$P_S = \alpha_S S D \tag{2}$$

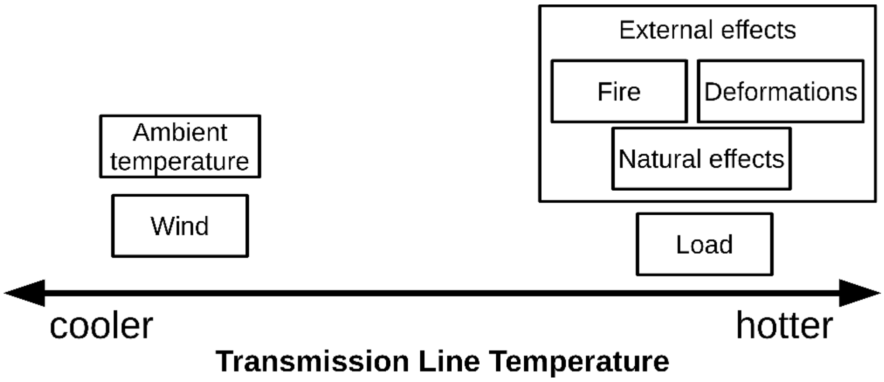

Fig. 1. External factors affecting the transmission line temperature.

2. Experimental Setup

It is important to map the temperature of power transmission lines in order to detect malfunctions in advance. Temperature measurement can be performed at certain intervals on the line. Wydra et al. [32] developed a LoRa Communication system for measuring the line sag and temperature by using sensor nodes. However, numerous sensors are needed for this type of measurement. Continuous data from multiple sensors also needs to be processed. However, in this article, a single-sensor approach was adopted. The temperature of the power transmission line varies according to various factors. The temperature generally does not change suddenly as it is dependent on both internal and external factors, which store potential energy and require time to adapt. Therefore, it is unnecessary to constantly measure the temperature at each point of the line. If the temperature of intermittent points of the line is measured at certain time intervals, the general temperature profile can be created. In this study, temperature was measured by the inspection robot moving on the line [34, 35]. Thus, the temperature profile of the whole line was created with the data received continuously while moving at a constant speed on the line.

In order to show the operation of the system, a mini-scale power transmission line was installed in the laboratory. The experimental environment is shown in Fig. 2. 90 [m] long transmission line consisting of 15 [m]-span fragments were set up. The line sagging was 40 [cm] at the middle point of each fragment. Conductor was chosen as 1/0 AWG Raven (AL (6/.1327), steel (1/.1327)). Although the line has been prepared according to the medium-voltage standard, it was not a live transmission line. There is no medium-voltage infrastructure in the laboratory. In the study, it was prioritized to create the temperature profile of the line. For this reason, the system was not operated on the live transmission line. The temperature of the line was measured between the starting point and finishing point. A certain point of the line was heated from the outside by an artificial heat source, which is shown in Fig. 2. This point simulates a faulty situation in real power transmission line. The fault might have occurred due to any of the reasons mentioned in Introduction Section. The ambient temperature of the experiment was measured as 24 ºC.

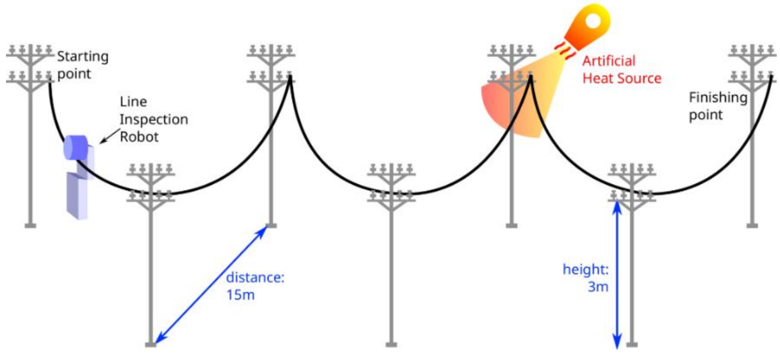

Fig. 2. Experimental setup.

An LPG blowtorch and a blower fan were placed as the artificial heat source at the connection point shown in the figure. Heat source was placed 50 [cm] away from the line and was directed towards the line. It heated both the conductor and the surrounding environment. DHT22 digital temperature and humidity sensor was used for measurement. It provides a digital output with 0.1ºC temperature resolution. The low cost of the sensor is very advantageous. However, standard measurement interval was 2 [s], which is quite long. Therefore, movement on the line had to be slowed down in accordance with this period.

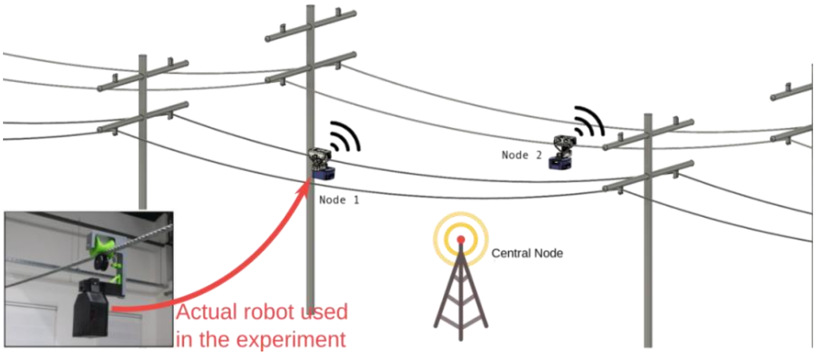

Fig. 3. Use case.

An example implementation to illustrate the use case is given in Fig. 3. One or more power transmission lines can be mapped by robots that communicate with each other and with the central node. Thus, information about the instantaneous state of the line and the environment can be obtained with the temperature map observed from the management center.

3. Temperature Measurement and Mapping

In the experimental setup, the temperature was measured while moving with a linear speed of 120 [mm/s]. The temperature was measured every 2 [s] during movement. Horizontal distance travelled relative to the ground is less than the linear velocity because the line was sagged. The temperature measured across the entire line against the horizontal distance is shown in Fig. 4. Measured instantaneous temperature can be associated with the position of the line. Thus, it can be known what the temperature is at what point of the line. During the experiment, the ambient temperature was changed in order to simulate external (natural) factors (weather conditions, etc.). This change was kept much lower than the temperature level of the artificial heat source emulating the fault condition.

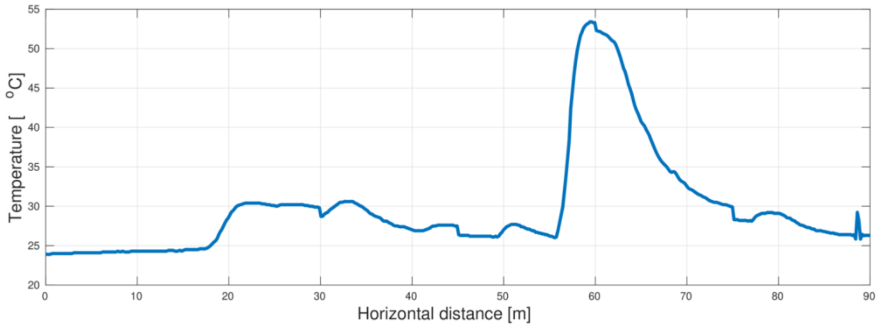

Fig. 4. Transmission line temperature.

Colour map is a more suitable way to show the transmission line's temperature profile. In this way, it can easily be seen at which point of the line the temperature has increased and control is required. The temperature map placed on top of the displacement graph is shown in Fig. 5. Temperatures between 20-55ºC are colour coded in the figure. Accordingly, the temperature profile of the entire line is visualized. A temperature map is given using a colour scale to show the method's output. By showing electric posts and line sagging in the visual, clarity is increased. Accordingly, the line operator will be able to see the line temperature not only as a meter-based location but also as a relative distance from a specific post. Thus, the system can give the exact position to the team that will intervene when necessary.

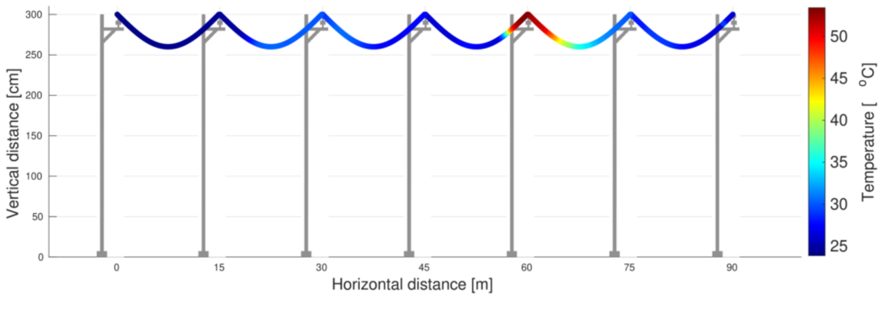

Fig. 5. Transmission line heatmap.

The experiment in this study took place in a limited laboratory environment. Line robot's communication was designed to send data over Wi-Fi. Communication was not possible with this method in the outdoor environment and long lines. Long-distance communication protocols such as 5G, LoRa, etc., can be applied for extended use on the actual transmission lines. Currently, the battery life of the robot is ~200 minutes. Depending on the need, the battery capacity can be increased and used at a more extended range. The concept's effectiveness has been demonstrated experimentally. The temperature range can vary and can be easily adapted for different environments.

4. Discussion

The temperature profile of the power transmission line is created in this study. It helps to detect situations such as overload, environmental factors, and physical wear and helps for taking precautions. In the experiment, an artificially heated part of the line is detected and shown in a temperature map. There is no other study in the literature in which the temperature map of the transmission line was drawn. Other transmission line robots mostly analysed the image of the line. In this study, unlike the others, the temperature of the line was measured instantaneously and matched with the location. In this respect, this study is different from its counterparts in the literature. In this study, the ambient temperature was measured with a temperature sensor on the line robot. It has been shown as the concept that changing temperature along the line can be mapped. Validation of the measured temperature with an external sensor is not included in this study. This validation can also be added in future studies.

5. Conclusions

This study aims to map the temperature profile of power transmission lines. The transmission line robot was moving at a constant speed measured and map temperature. The temperature profile provides instrumental data for detecting some faults that may occur in the near future. It provides early warnings for overload, environmental factors, and physical wear and helps take precautions. In the experiment, an artificially heated part of the line was detected and shown in the temperature map. In future studies, the relationship between temperature change and fault types will be investigated. Thus, an autonomous system can be developed for the early detection of faults.

An experimental study in the laboratory environment is presented in this article. Unlike the examples in the literature, the transmission line temperature was measured and mapped robotically. Other examples in the literature focus on mathematical models to estimate the line temperature using load measurement. Instant measurement could be made with the method presented in this paper. Thus, it has contributed to the literature in the field of instrumentation. The relationship of line temperature with overload, environmental factors, and physical wear has been extensively studied in the literature. Therefore, this article does not include those details. Instead, it is aimed to measure the line temperature with low-cost equipment. It is thought that its accuracy will increase when it is integrated with currently used mathematical models.

Nomenclatures

D	Conductor diameter
k_j	Estimated parameter

S	Solar radiation
Greek Symbols	
α	Absorptivity
α_t	Temperature coefficient of resistance-per-degree
Abbreviations	
LoRa	Long Range Communication Network
LPG	Liquefied petroleum gas
LSTM	Long short-term memory

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