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PDF Based Icing Image Recognition Applied to Online Early Warning System for Transmission Lines

Xin Yin[1], Xu Chen*[2], Ertao Lei[2], Jinrui Tang[2], Hong Wang[1], Minghao Wen[2]
[1]School of Electrical and Electronic Engineering, The University of Manchester,
Oxford Road, Manchester M13 9PL, U.K.
[2]State Key Laboratory of Advanced Electromagnetic Engineering and Technology,
Huazhong University of Science and Technology, Wuhan 430074, China
*Corresponding author, e-mail: chenxu_hust@qq.com

Abstract

This paper proposes an online early warning technique and the probability distribution function (PDF) based icing image recognition for overhead power transmission lines. The main functionality of the online early warning system for overhead transmission lines firstly suggested in this paper is the early warning of icing, forest fire, lighting, insulator flashover, conductor galloping and invasion which is based on a scheme of the online inspection system for the transmission lines with optical fibre communication technology. As a case study, the early warning of icing is discussed in this paper and a comprehensive icing early warning scheme has been proposed: the local meteorological conditions and mechanical data are applied for the initial criteria of the icing early warning system, and the PDF based image recognition technology is then used to finally decide the icing condition of transmission lines, which can be more effectively dealt with than complex pictures acquired at towers.

Keywords: *overhead power transmission lines, online early warning, probability distribution function, icing image recognition*

1. Introduction

The power system is one of the most complex industrial systems in the world, whose functionality is to transform the primary energy into electrical energy by power generating devices. The electricity is distributed to the centre of load by power transmission, transforming as well as distribution system, and then converted to other kinds of energy among which power transmission system takes a responsibility for power energy transmission. Faults of transmission lines will not only pose a threat to the safe and stable operation of power systems itself, but also cause power users' huge loss. As the high pace of modern power grid and smart grid constructions, the high-voltage-level transmission lines have become more and more popular, which requires high reliability for power supply of the transmission lines. However, transmission lines may easily broke down and even become a disaster because they are exposed in the air all year long and influenced by the adverse climate. Some transmission lines are even set across the bogs, deserts and mountains. Therefore, we need to conduct in-depth study on the early warning technology of transmission line so that we can find faults of transmission line in time, which guarantees the safety operation of transmission line and its devices.

To overcome the difficulty of transmission line inspector and early warning, an inspection system for the transmission line is proposed in this paper, which consists of tower terminals, fibre-optic communication systems and the master station. Due to large amount of real-time data, such as images and pictures at each tower along with long-distance lines, a novel fibre-optic communication system is presented, which is based on the fusion splicing techniques of the optical fibre composite overhead ground wires (OPGWs) and Ethernet passive optical networks (EPONs). The information of the early warning is obtained from the online inspection system of overhead transmission lines. Papers [1] have analyzed the real time performance of the EPON system for better monitoring.

Based on the information acquired by the transmission line early warning system, influences of all kinds of disasters on the transmission line and corresponding early warning

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methods can be studied. The main functionalities of the online early warning for overhead transmission lines that are suggested in this paper are early warning of icing, forest fire, lighting, insulator flashover, conductor galloping and invasion. Only some of those functionalities are selected and used according to different areas in practice. Among natural disasters that transmission lines suffer, icing is one of the most serious threats. The extra weight caused by icing will cause severe sag [2], and then the discharge to the objects below will cause the short circuit. Meanwhile, the conductor galloping would possibly occur when the shrouded ice falls off. Even more, severe icing will cause the rupture of the transmission lines and the tower collapse. Traditional methods for icing monitoring and corresponding devices can be divided into two categories: One type uses sensors [3, 4] like gravity sensor, capacitance sensor, vibration sensor and climate sensor, which has disadvantages of less information and accuracy. The other uses machine like deicing robot [5] and aircraft [6], which is expensive and not all-whether.

The paper is outlined as follows. Section 2 introduces the construction of the online early warning system for overhead transmission lines and schemes of six practical online early warning. Section 3 chooses the worst disaster introduced in section 2 and proposes the icing image recognition based on PDF as well as comprehensive icing warning method. The last two sections are the experiment results of the icing image recognition based on PDF and conclusions.

2. Online Early Warning System for Overhead Transmission Lines

2.1. Construction of the Online Early Warning System for Overhead Transmission Line

The proposed online early warning system for the transmission lines consists of tower terminals installed at each tower along the transmission lines, fibre optic communication systems and the master station, which is shown in Figure 1. The long-distance transmission lines are supported by the insulators, which are installed at the transmission towers along the route. The tower span is generally several hundred meters, and the tower terminals are installed at each tower. The local monitoring data sampled by the tower terminals are transmitted to the master station through the fibre-optic communication systems based on the optical fibre composite overhead ground wires (OPGWs).

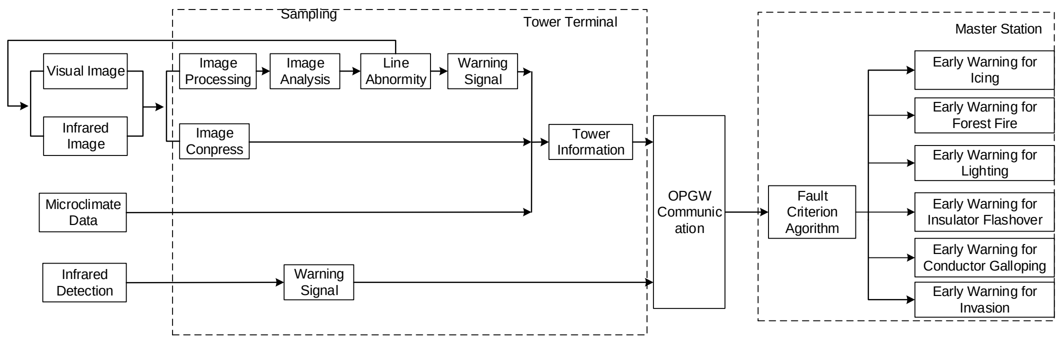


Figure 1. Online early warning system for the transmission lines

The tower terminal consists of the measuring units, processing unit, energy supplement unit and optical network unit (ONU). The measuring units are used to sample the desired data, and the processing unit is used to collect the monitoring data, pre-process the data, upload the data and receive the command sent from the master station.

Fibre-optic communication is realized based on the fusion splicing techniques of OPGW and Ethernet passive optical networks (EPONs). The system can guarantee the real-time communications between each tower terminal and the master station. The functionalities of the master station mainly include data storage, data analysis, data queries, remote monitoring, remote control, system management and system configurations.

2.2. Online Early Warning Scheme for Overhead Transmission Line

The contents and targets of the early warning for the transmission lines should be identified based on the characteristics of transmission lines and the environment. It should meet the early warning requirements of all transmission lines catastrophes, including the catastrophes caused by typhoon, lightning, mountain fire, tree growth and engineering construction. In order to realize the early warning, the supporting system is needed to obtain the monitoring data in real time. Through analyzing the monitoring data, the potential threats can be distinguished, and then early warning and fault alarm can be sent out.

After analyzing the influences caused by the disasters, the contents of the early warning for transmission lines is suggested as follows: early warning of the overhead line icing, the mountain fire in the transmission corridor, the lighting, the insulator flashover, the conductor galloping and invasion. These contents are different according to the fields. The detailed principle will be discussed as follows.

1) Online early warning for icing

The icing of overhead line mainly occurs in the south of China, and the meteorological conditions [7] which lead to icing generally includes: 1. the temperature and the equipment surface temperature is below 0degree centigrade; 2. air relative humidity is above 85%; 3. wind speed is greater than 1m/s. However, the exact relationship between existing power facilities icing conditions and meteorological factors is still a major problem, and the accuracy of deciding whether overhead line is icing is very low only by the meteorological condition. While the existing methods, such as weighing method and method of lead tilt remain to be improved in terms of accuracy. Image information of ice warning is favoured by scholars and operation departments for its intuition and reliability. However, existing methods are using photos taken at the scene and deciding the ice-covering condition by edging detection and contradistinction of the photos [8] before and after the icing. These methods have disadvantages of being affected by the image resolution sensitively and poor adaptability under different ice conditions. In order to improve the accuracy of early warning of the transmission lines icing, comprehensive early warning method based on the analyses of the real-time images can be used. Because the transmission lines ice cover is likely to happen only in a particular climate and geographical environment, meteorological conditions combined with the mechanic variation can be used as the early warning criterion, in which meteorological data is provided by the micro-meteorological system. Then the PDF-based image identification proposed in this paper is used for early warning. At the same time, because the temperature of the icing position is lower than the normal temperature, the infrared data according to the monitoring position marked in the visible images can be used to improve the accuracy of the early warning.

2) Online early warning for forest fire

Overhead line corridors are often across the mountains and the wilds.Forest fire would pose a serious threat to the safe operation of lines. The traditional real-time forest fire monitoring based on 3S technology [9] can't monitor at all-weather and full time condition. Its location accuracy is not high and thus the small range of fire early warning cannot be in time. The novel idea is as follows: firstly the infrared detection is used as the initial criteria, then the monitoring visible images are used to preliminary decide the mountain fire based on the image recognition technique. Finally, combined with infrared image, peripheral security environment and meteorological environment data, the early warning can be made. It can improve the accuracy of the transmission line corridors forest fire warning.

3) Online early warning for lighting

The lighting occurs frequently in many areas. The huge electromagnetic effects, mechanical effects and heating effects of the lightning currents will result in serious devices damage even if there are many lightning protection devices. Now the methods of lighting early warning are mostly based on the overvoltage monitoring caused by lightning or the overcurrents monitoring. Other methods are used to locate the lighting area based on the lighting sensors and GPS. The suggested method about the lighting early warning contains two aspects: a) based on the lighting monitoring data and the local meteorological data, the frequency of the lighting can be obtained. When the frequency is off-limits, the optimal control measurements should be taken, such as reducing the transmission load; b) the current in the overhead ground wires is monitored to locate the lighting location.

4) Online early warning for insulator flashover

In the snow melting or other severe weather conditions, the solid, liquid and the gas-borne particles will cause the decrease of the insulator electric strength. Then a flashover will occur on the insulator [10] and the power outage will appear. At present, the early warning methods of the insulator flashover are mostly based on the leakage current monitoring or the equivalent salt deposit density monitoring, the reliability of which is not enough. Methods based on the local meteorological data and the methods based on the sound wave are suggested to improve the accuracy of the early warning of the insulator flashover.

5) Online early warning for conductor galloping

The conductor galloping [11] would occur under the conditions of the strong wind (typhoon), transmission lines icing etc. The conductor galloping can cause interphase flashover, fitting damage, etc. Then line trip and blackout will occur. The according sensors should be used for early warning of the conductor galloping with the transmission line model. The sensors include the vibration sensors, displacement sensors, acceleration sensors, etc.

6) Online early warning for invasion

Tree growth and the passing machineries may cause the short circuit of the transmission lines. Then the power outage or the transmission line damage will occur. But the early warning of the invasion has not been greatly addressed. The suggested methods for the early warning of the invasion contain two aspects: firstly the conductor sag would be identified based on the operating parameters of the transmission lines and the local monitoring data, such as the temperature, then the video surveillance is used for the early warning of invasion. For the growth of the tree below the conductor, the methods based on the growth speed can be used as the initial criteria.

3. Icing Image Recognition for Overhead Power Transmission Lines

In this section, icing image recognition for overhead power transmission lines based on PDF is explained and a comprehensive icing warning method for overhead transmission line is proposed. The discussion are made in two sub-chapters.

3.1. Icing Image Recognition Based on Probability Density Function

In order to simplify the processing, we usually use gray image. And we establish the coordinate system, in which define down direction as X positive axis, the right direction as Y positive axis. Then a ray image of M line, N line can be expressed as

$$\boldsymbol{f(x,y)} = \begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N\text{-}1) \\ f(1,0) & f(1,1) & \dots & f(1,\mathrm{N\text{-}1}) \\ \vdots & \vdots & \ddots & \vdots \\ f(\mathrm{M\text{-}1},0) & f(\mathrm{M\text{-}1},1) & \dots & f(\mathrm{M\text{-}1},\mathrm{N\text{-}1}) \end{bmatrix} \tag{1}$$

Where $f(x,y) \in [0,2^k - 1]$, $x \in [0,\mathrm{M}-1]$, $(x,y) \in SS$, $\mathrm{y} \in [0,\mathrm{N}-1]$.The gray level is $L = 2^k$, the dynamic range of image is $[0,\mathrm{L}-1]$. The higher resolution the spatial and gray have the image is more delicate.

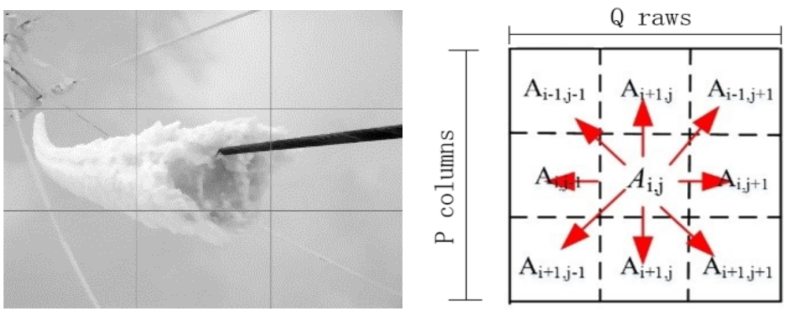
Then the PDF [12] for a discrete variable gray scale *i* is defined as Equation (2) and the CDF (cumulative distribution function) is defined as Equation (3), where the threshold of the icing target is $s < f(x,y) < t$.

$$p(\mathrm{i}) = \frac{1}{M \times N} \sum_{f(\mathrm{x,y})=1} i \tag{2}$$

$$H(f) = \sum_{i=0}^{f} p(\mathrm{i}) \tag{3}$$

The steps of the PDF based icing image recognition are as follows.

1) Image preprocessing: the image preprocessing includes RGB to gray processing and median filter. Converting RGB to gray results from that the gray image needs less storage and can be processed quickly with low performance hardware. What's more, the detail of gray image is sufficient for icing decision. The median filtering is a method of ranking the pixel gray value within a sliding window and using the median instead of the central gray pixel value. The method is a nonlinear smoothing method, and it can deduce impulse interference of salt and pepper noise effectively. It can also protect the edge from diming effectively. Considering the practical performance of the median filter, 7×7 masking median filter was used in this paper.



(a) The preprocessed image (b) The partition blocks

Figure 2. Diagram of space-based image segmentation

2) Partitioning: The image is partitioned into P×Q blocks in space shown in Figure 2, block is denoted as symbol A(i, j), where $i \in [1,P]$, $j \in [1,Q]$.

3) Calculation: The image recognition needs to detect the comparability of gray scale distribution of two adjacent blocks. Suppose that the segmentation has been done in a rule and the image is segmented into m×n different blocks (*k*×*k*) which are not overlapped. Then cumulative grayscale distribution histogram, which is the Cumulative Distribution Function in the sense of probability, can be calculated according to (2) and (3). Actually, it is the gray level distribution function (CDF).

4) Icing criterion: To decide the area of icing, the similarity must be analysed among neighbour's pixels blocks of a picture, or the same blocks in pictures. The accumulative histogram function curve of adjacent blocks $H_1(f)$ and $H_2(f)$ are carried out as shown in Figure 3. If the gray distribution of the two curves is similar, it is illustrated that the two curves belong to the same area. For the growing and combining of areas, it is necessary to give a standard to measure the similarity. The most commonly used standard is Kolmogorov-Smimov criteria and Smoothed-Difference criteria, as shown in Equation (4) and Equation (5).

Figure 3. The grayscale distribution features of the neighboring areas

$$\max_f |H_1(f) - H_2(f)| \begin{cases} < T_1 & region\ merging \\ \geq T_1 & stay\ the\ same \end{cases} \tag{4}$$

$$\sum_f |H_1(f) - H_2(f)| \begin{cases} < T_2 & region\ merging \\ \geq T_2 & stay\ the\ same \end{cases} \tag{5}$$

If we choose as the initial search point, we can search the eight adjacent blocks as shown in Figure 2(b). If the block satisfies the K-S criteria, it will be combined with the start block. Then we choose the new block as the central block and search its eight adjacent blocks until no blocks meet the criteria. This paper uses Kolmogorov-Simimov criteria to judge the similarity of blocks.

3.2. Comprehensive Icing Warning Method for Overhead Transmission Line

In order to improve the accuracy of the transmission lines ice early warning, comprehensive early warning method based on the analyses of the real-time images can be used. Because the transmission lines ice cover is likely to happen only in a particular climate and geographical environment, meteorological conditions combined with the mechanic variation can be used as the early warning criterion, in which meteorological data is provided by the micro-meteorological system. Then the PDF-based image identification proposed in this paper is used for early warning. At the same time, because the temperature of the icing position is lower than the normal temperature, the infrared data according to the monitoring position marked in the visible images can be used to improve the accuracy of the early warning. The specific processes are shown in Figure 4.

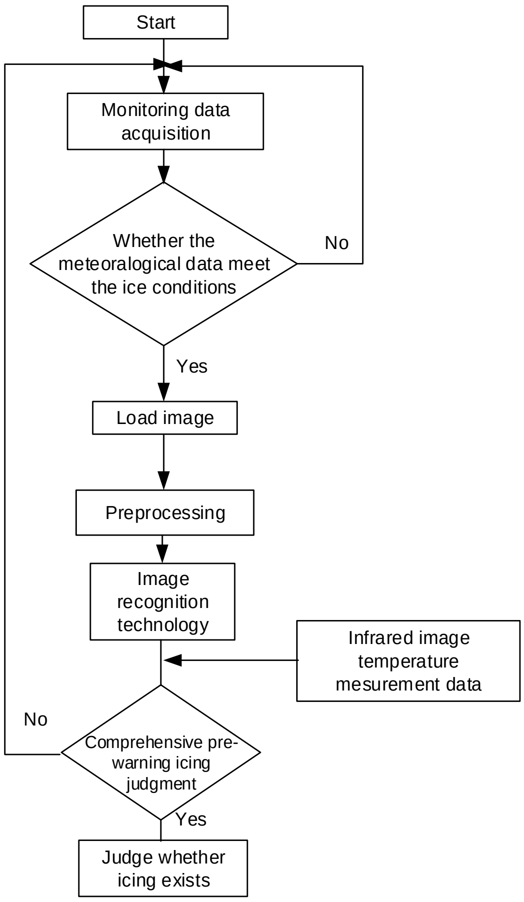
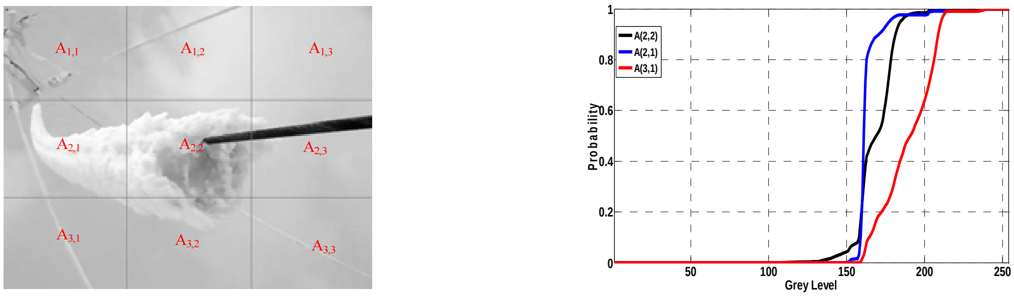


Figure 4. The comprehensive early warning method for transmission line icing

4. Experiment Results

To verify the icing image recognition based on PDF, experiments have been made as follows. In Figure 5, the icing transmission line is extracted by calculating CDF (Cumulative Distribution Function) of adjacent blocks having been divided. We divide Figure 5(a) into 3×3 blocks and each block has a resolution of 200×266. Three adjacent blocks have been labelled as $A_{2,1}$, $A_{2,2}$, and $A_{3,1}$ in Figure 5(a) by spatial segmentation. Using the algorithm of partitioned matrix, the CDF of three blocks are shown in Figure 5(b).



(a) diagram of the adjacent blocks (b) CDF of block A(2,1), A(2,2) and A(3,1)

Figure 5. The partitioning and CDF calculation results

The previous experiment based on 3×3 blocks of segmentation can judge the area, but roughly. To get the accurate area where the icing is, there are more segmentation blocks are made in Figure 6.

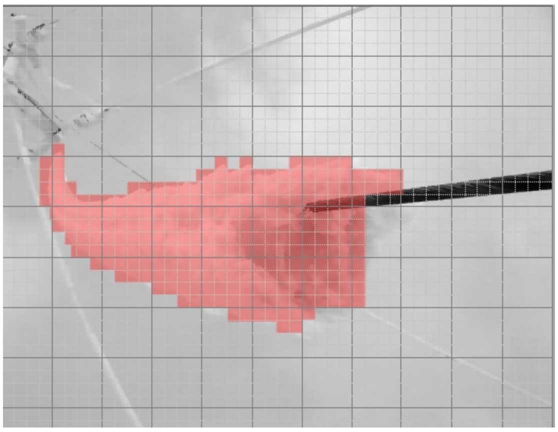


Figure 6. Partitioning into more blocks and using icing criterion

In Figure 6, the image is divided into 8×11 blocks and the searching unit is a 4×4 area in each block. The starter of the search algorithm can be one arbitrary point identified in block $A_{2,1}$ and $A_{2,2}$ as shown in Figure 5(a).

5. Conclusion

The basic task and principle of the early warning is proposed in the paper. Base on this, the supporting system and the hierarchical construction of the early warning technology is discussed. The real-time image of the transmission line and other related information is collected by the remote measuring and controlling terminals installed at each tower. The mass information is transferred timely by passive optical fibre communication technique based on

OPGW. An effective early warning mechanism is established by synthetically analyzing monitoring data. Based on the supporting system, the mission and principle of six early warning are discussed.

Based on the characteristic of icing early warning, the PDF-based image recognition technology is applied for icing early warning. The synthetic icing criterion is established combined with the microclimate, mechanics measurement and infrared thermal image, which can enhance the accuracy and real-time performance of the early warning. The simulation results based on the actual icing image from the scene prove the validity of the proposed PDF-based image recognition method.

Acknowledgements

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