Development of Infrared and Ultraviolet Detection Technology in Electric Power System

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Abstract. As countries increasing electricity demand, the power grid has been expanding. The security and stability of power system becomes extremely important. The traditional examination method cannot meet the demand of the existing. More and more testing methods have been appeared. This paper mainly introduces the development of infrared detection technology and UV detection technology in the power industry. The application of multi-channel detection technology is extended. Beyond that, the current research on multi-channel portable detection equipment and the development direction of the current power detection industry are introduced in this paper.

Introduction

With the constant growth of national demand for electricity and the ceaselessly enlargement of construction scale for power grid, the power load has been increasingly rising, and electrical equipment have been staying in the working status of outdoor high-voltage, high-temperature and high-load for a long period. In the event of damages or failures, it may cause great economic losses, therefore detecting the security for all stages of the power system is of great significance. In addition, the number and complexity of various types of electrical equipment in power system has been increasing, so many of the traditional means of detection and maintenance are no longer applicable, which means comprehensive detection technologies are certainly the development directions of electrical detecting equipment.

Detection methods for traditional electrical equipment include: observation method, ultrasonic detection method, on-line monitoring method of leakage current, however, all of which have certain limitations in practical applications. Eye observation method is one of the most common methods, but a great number of electrical equipment accidents occur in the absence of visible light, so usually people can only hear the sound of corona discharge like "Shoon~~", without catching any phenomenon of electric discharge; ultrasonic detection method hardly can intuitively and accurately position the discharge spots at a far distance, and it's especially harder while multiple spots are discharging; on-line monitoring method of leakage current needs the installation of corresponding measurement equipment in advance, which is not suitable for a broad promotion and usage [1].

In recent years, optical detection methods have become more and more important in power detection systems. At present, optical detection methods used in the power systems mainly contain three categories: infrared imaging technology, UV imaging technology and visible-light HD monitoring technology [2]. Due to the different nature of the failure to be detected, the three methods are independent of each other in hardware, so inspection personnel need to carry different equipment to detect failures in different stages of the circuit system. Therefore, it's not conducive to the safe and efficient operation of the power detection, and the development of a portable three-in-one imaging equipment integrated with ultraviolet/visible/infrared is of practical significance.
Development of Infrared Imaging Technology

Infrared imaging technology can be effective in monitoring and diagnosing the thermal defects of electrical equipment, constantly detecting early failure or defects of electrical apparatus under operating conditions, as well as in detecting latent failures which cannot be detected in the traditional manner [3].

In the mid-1960s, infrared thermal imaging technology was first used in the industrial sectors, and later on Sweden State Power Company manufactured AGA series of thermal imagers and applied them to the inspection of power systems, which turned out to be a huge success [3]. Since then, power systems of countries gradually began to widely use the infrared thermal imaging technology. In China, the infrared imaging technology started late. In the mid-1980s, the infrared thermal imaging detection technology started to be widely used in the domestic industries, particularly in the power and chemical industries. Now, most departments of our power systems have been configured with infrared thermal imagers [3]. In 1998, our country developed a guideline for infrared diagnosis of power; on the basis of actual on-site measurement and simulation experiment for typical failures of certain equipment, National Economic and Trade Commission issued and implemented the "Application Guideline for Infrared Diagnosis Technology of Charged Equipment" (DL/T66421999) in 1999, which contains 40 thermal imaging maps of typical failures. This guideline was a mark that infrared thermal imaging detection and diagnosis technology of Chinese power systems had taken a new step on the road of standardization development [3].

Development of UV Imaging Technology

"Solar-blind" corona detection technology is a new technology of corona discharge detection. This technology can observe clear UV images in daylight environment, which can accurately detect discharge locations [3]. Due to its light weight, small size and easiness to carry, the UV Imaging detector adopting this technology has been widely used.

In 1981, power experts from former Soviet Union first applied UV imaging technology to power systems. The wavelength detected by the early UV imaging instrument was within a relatively wide range, only available for night detection; in the late-1990s, research personnel from United States, South Africa and Israel developed a solar-blind type UV imaging instrument, which overcame the defects of the Russia UV electronic optical detector which could be only used for night detection and could observe the corona phenomenon under the bright light, and it has been used in more than a hundred of global high pressure laboratory, research institutes and service agencies; in 1999, EPRI launched the "Inspection Guideline for Corona and Arcing of Overhead Transmission Lines" compiled by Dr. Andrew Phillips, which classified the different discharge defects of high voltage electrical equipment and also contained many UV maps of extensive on-site detection. It became the reference guideline for UV Imaging detection of electrical equipment [5].

UV imaging technology in China first came from the military filed. In 1980s, this technology only had development and application in the military aspects,. In early-1990s, with rapid development of other countries in the world using UV imaging technology, corresponding detection equipment entered the Chinese market, and the power systems in China gradually got awareness of its importance and effectiveness[1]. UV imaging technology and its application in domestic power systems was founded in 2002, and currently our country has developed completely homemade UV imagers [6]. Nanjing University has achieved excellent research results in out-band rejection technology, and it presented solar blind UV detection theory BLUP to the world for the first time, which put forward systematic evaluation indicators for solar-blind UV detectors and laid a theoretical foundation for the development of UV imaging instrument.

Through many years of field experience and performance comparison, the performance parameters and technological level of domestic products have been greatly improved. They have been gradually applied to vehicle-mounted and airborne platforms and have also had a capacity for mass production. Their performance can compete with that of foreign equipment, such as the ZF-S2 full solar-blind UV Corona detector manufactured by Nanjing University 5D Technology Co., Ltd..
Table 1 shows a comparison of performance parameters of mainstream UV imaging equipment at home and abroad which are currently used in national grid.

Table 1. The comparison of property of Ultraviolet imaging device.

<table>
<thead>
<tr>
<th>Equipment name</th>
<th>Weight</th>
<th>Sensitivity</th>
<th>View</th>
<th>Overlap accuracy</th>
<th>Out-of-Band rejection</th>
<th>Operation</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Israel SuperB</td>
<td>3.3(kg)</td>
<td>2.20×10⁻¹⁸</td>
<td>5°×3.75°</td>
<td>≤1mrad</td>
<td>Good</td>
<td>Simple</td>
<td></td>
</tr>
<tr>
<td>Nanjing University 5D</td>
<td>3.3(kg)</td>
<td>3.00×10⁻¹⁸</td>
<td>5°×3.75°</td>
<td>≤1mrad</td>
<td>Good</td>
<td>Simple</td>
<td></td>
</tr>
<tr>
<td>South Africa CoroCAM 6D</td>
<td>1.9(kg)</td>
<td>2.05×10⁻¹⁸</td>
<td>8°×6°</td>
<td>≤1mrad</td>
<td>Slight light leakage</td>
<td>Complex  Operation</td>
<td></td>
</tr>
</tbody>
</table>

**Multi-channel Detection Equipment**

Infrared imaging detection technology and UV imaging detection technology are technologies which are complementary rather than conflicting. As shown in table 2, the detection of high-voltage transmission lines should include UV imaging, infrared imaging and visible-light detection. Corona is the partial discharge phenomena on the surface, in which case the air generates ionization due to local pressure. It occurs in the early failure stages of electrical equipment. Due to little heat, infrared detection equipment usually cannot detect it; infra-red detection usually produces hot spots at high resistance, which occurs in late failure stages of the electrical equipment. Those seen by UV Imaging often cannot be seen by infrared imaging, in return, the ones seen by infrared imaging usually cannot be seen by UV Imaging, therefore two types of imaging equipment form a technical complement in the detection of transmission lines, which can make up for the reserved space of single equipment detection [8].

Table 2. Comparison of infrared detection and UV detection.

<table>
<thead>
<tr>
<th>Project</th>
<th>UV ultraviolet detection</th>
<th>IR infrared detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range(um)</td>
<td>0.24-0.28</td>
<td>8-14</td>
</tr>
<tr>
<td>Sensitivity range of instrument</td>
<td>Ultraviolet radiation</td>
<td>Infrared radiation</td>
</tr>
<tr>
<td>Function</td>
<td>Insulation defects; corona; arc</td>
<td>Resistance defect; humidity anomaly</td>
</tr>
<tr>
<td>Strong light interference</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Scope of collection</td>
<td>Visible-light, UV Imaging</td>
<td>Visible-light, Infrared imaging</td>
</tr>
<tr>
<td>Weather conditions</td>
<td>High humidity and low pressure contributes to corona discharge</td>
<td>Interference detection at high temperature, and detect can't be done in rainy days</td>
</tr>
<tr>
<td>Detection stage</td>
<td>Generally detect defects in early stages</td>
<td>Often detect defects in late stages</td>
</tr>
</tbody>
</table>

In this regard, the researchers carried out studies on detection technology of three-spectrum of UV/IR/visible. As for three-spectrum detection technology, at present, foreign UV power monitoring instruments mainly include solar-blind UV imaging products from Israel Ofil company and South Africa CoroCAM company, among which, CoroCAM is developing a multi-spectral solar-blind UV imager CoroCAM 8 (CoroCAM Multi-Spectral Solar Blind Cameras), and it will be released soon. This imager has channels of visible, infrared and solar-blind UV. The visible channel can be used to locate the solar-blind UV images, and the infrared image channel and the solar-blind UV image channel can be integrated, which just adopts a variety of monitoring instruments to detect power failures. The schematic diagram of CoroCAM8 is shown in following Figure 1.
In addition, the article "Ultraviolet and Infrared Dual-Spectrum Spectrum On-Line Monitoring System of Power Equipment" refers to a new type of on-line monitoring system of power equipment, which is mainly composed of UV and IR dual-spectrum detection module, embedded system module, temperature and humidity measurement module and wide-area wireless communication module [9]. The schematic diagram of dual-spectrum on-line monitoring of electrical equipment is shown in following Figure 2.

Development of Detection Equipment
UAV Power Inspection System
With the constant progress of sensors and remote sensing technologies, using the multiple sensors of unmanned helicopter to obtain more source data may have become possible. Using airborne sensor system for power inspection is high-tech widely used both at home and abroad in recent years. By adopting this technology, we can directly obtain high resolution image and precise 3D information within the power line corridors through the flying of the UAV, as shown in Figure 3. By using this method, we can significantly improve the efficiency of line inspection work and largely reduce field work [10]. However, the load of the UAV itself is currently restricted, so it's difficult to control the flying condition and the flight planning is easily affected by the weather, with great difficulties in implementation; secondly, the inspection system of UAV raise higher requirements for airborne equipment, that is, high stability, light weight, high frame rates and high resolution and good closure, so this solution is more difficult to be popularized in the country.
Wearable Portable Inspection System

Wearable equipment are a computer system that we can wear, which is a new type of human-computer interaction. Jiangsu Electric Power Research Institute independently developed and the promoted the wearable personal infrared inspection equipment, as shown in Figure 4. Miniature and integrated individual inspection equipment complies with the operation habits of first line inspection personnel, and its convenient operation provides a new model for detection.

The article “Research of Security Guardianship Platform Power Job of Based On Wearable Technology” applies the technology of information, communication and sensing to security helmets and electronic watches. By interconnection with the guardianship system through wireless communications technology, we can implement the functions such as personnel positioning, voice calls, sound and video recording, lighting, photographing, infrared temperature measurement of equipment, near electric alarm, SF6concentration monitoring, remote information query, life signs monitoring, automatically alarm of falling, and emergency alarm. security helmets and smart watches in this system communicate with each other via Bluetooth. The positioning between operation personnel and the data transmission between the remote monitoring systems is implemented through wireless local area network (Wireless Fidelity, Wi-Fi) within the substation. If it's away from the substation, this will be implemented through global positioning system (Global Positioning System, GPS) and fourth generation (the 4th Generation, 4G) wireless communication mode [11]. This system can offer references for applications of wearable equipment in power industries and other industries, and the design of its security monitoring platform is shown in Figure5.
Recently, Jiangsu Electric Power Research Institute cooperate with Nanjing University 5D Technology Co., Ltd. carry out the technology research of wearable three-in-one image detection equipment based on Ad-Hoc network. This project comes with the information platform from Ad-Hoc network, which can realize the full-day whole-network inspection, as well as the real-time access and status alert of substation operation data. It can also automatically generate inspection reports, effectively reduce the inspection workload of the substation, greatly increase inspection efficiency and failure detection rates, and offer comprehensive support to the operation maintenance and the condition-based maintenance of equipment, and its structure is shown in Figure 6. This project will highly integrate the three detection equipment of UV, infrared and visible, and then form a small wearable detection equipment, which can collect three band images of typical defects of electric equipment and then conduct a comprehensive analysis and diagnosis for the three-spectrum integration.

Due to the fact that in the solar-blind UV images of the system, there is electric corona image but no environment reference, it's hard to identify defect location, therefore, we need to provide an image of axial light path as a reference, so as to design a common optical path system for UV and visible. This system includes UV lens, high performance UV filter light tablets, UV detectors, spectroscope, HD visible-light camera, and the image processing and transmission system. Infrared module mainly consists of transmissive optical system, uncooled focal plane and detection circuits. The infrared module convert a temperature signal of -20–220°C into an analog voltage signals of 0–5V, and then provides an embedded system module for image analysis and processing. In reality, the signal is very weak in the thermal imaging distribution of the infrared radiation of each part of the target object to be measured, and it's lacking in the sense of layering and dimension compared with the visible light, therefore, in the actual action process, in order to more effectively judge the infrared hot field of the targets to be measured, we often adopt some auxiliary measures to increase the practical function of the instrument, such as image brightness, and contrast control, actual correction, false-color depicting, and other altitude and histogram for the purpose of operation and printing. The optical system design of each module has made a project assessment from the perspective of high integration, small volume and light weight, so as to balance sensitivity and
volume weight and select the optimum optical design. Meanwhile, the stand-alone module ensures that the three images make a good overlap, and also it's assisted by the precise structural design and machining. Currently, the control weight of this project is within 1.5kg, which greatly reduces the burden on inspection personnel. The equipment is designed to be wearable, so as to liberate the hands of inspection personnel and reduce their burden, which is convenient for them to carry other equipment to enhance inspection efficiency.

<table>
<thead>
<tr>
<th>Detection methods</th>
<th>UAV systems</th>
<th>Portable wearable systems</th>
</tr>
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<tbody>
<tr>
<td>Equipment requirements</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Flexibility</td>
<td>medium, limit by the weight of carried equipment</td>
<td>High, flexible movement for detection</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>high Maintenance costs, difficult to maintain</td>
<td>Low maintenance costs, easy to maintenance</td>
</tr>
</tbody>
</table>

**Summary and Outlook**

This paper summarizes the development of IR and UV imaging detection technology in the electric power industry. With the development of power systems, more comprehensive detection methods will be applied to the power systems, so as to ensure the safe and stable operation of power systems. The integrated three-in-one detection technology of UV, infrared and visible provides the power detection system with more comprehensive method of detection and diagnostics. This technology is able to conduct a full-day whole-system detection on the failure in each stage of the power systems, so as to improve the efficiency and security of power inspection, which will essentially become the development trend for failure detection of electric power systems.

With the constant development and update of inspection equipment, inspection methods are also in a continuous development. Wearable portable inspection equipment based on Ad-Hoc network can liberate the hands of inspection personnel, increase the mobility of inspection, enable the information transmission more efficient and make the work more secure. It is surely the future development direction of grid inspection.

**Acknowledgments**

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**References**


