Comparison of Pulse Terahertz and Continuous Wave Terahertz in Vacuum Charging Detection

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Abstract: The principle of detecting the vacuum degree of terahertz wave is discussed. The imaging principle, imaging characteristics, imaging speed, and price of pulsed terahertz and continuous wave terahertz are compared and analyzed. The conclusion shows that the pulse terahertz frequency is higher in the practicality of vacuum detection, but it is expensive, bulky and inconvenient to operate in the field. Continuous wave terahertz imaging has high frequency resolution, low price, short imaging time and practical more sexual.

Introduction

The degree of vacuum refers to the degree of leanness of the gas at an absolute pressure lower than one atmosphere, and the higher the degree of vacuum, that is, the lower the gas pressure. For the vacuum interrupter for vacuum circuit breakers, the national standard stipulates that the vacuum of the arc extinguishing chamber is at least 6.6×10^{-2} Pa. In the actual production of the power industry, the arc extinguishing chamber is generally repaired when the degree of vacuum is less than 1.33×10^{-1} Pa. This is because as the life of the vacuum circuit breaker increases, the vacuum degree of the arc extinguishing chamber will decrease. Under the action of the electric field, the probability of collision between the electrons and ions emitted by the moving contact and the static contact increases with the gas molecules, and the arc extinguishing chamber is charged. When the particles are enough, the breakdown will be formed. It is difficult to guarantee the insulation and arc extinguishing performance, and the short-circuit current or even the load current cannot be reliably broken, which jeopardizes the safety of the coal mine power supply and distribution system. Therefore, it is important to detect the vacuum degree of the vacuum circuit breaker.

From the current international and domestic development trends, as vacuum circuit breakers are the core switch types in medium voltage distribution switches, with the increasing level of manufacturing level and breaking voltage level in the power grid, the domestic and international smart grids and Based on the continuous development of the reliability inspection system, the vacuum degree charged detection method can detect the vacuum degree in real time and discover the deterioration of the vacuum degree in time, which becomes the new requirement and development trend of the intelligent high voltage vacuum circuit breaker.

Vacuum Detection of Vacuum Based on Terahertz Technology

Terahertz (THz) is a very unique electromagnetic wave. The terahertz wave is an electromagnetic wave with a frequency in the range of 0.1 to 10 THz (wavelength of 3mm to 30μm). The position is just between the microwave, millimeter wave and infrared optics, which are relatively well developed in science and technology, and are located in the electromagnetic spectrum. The position is shown in Figure 1. It belongs to the category of far infrared and sub-millimeter waves.

With the development of non-destructive testing technology, the application of radio-graphic detection technology in power equipment detection has become more and more extensive. In recent years, the application of X-ray detection technology in power equipment detection has been
gradually recognized by the industry. This technology is widely used in fault diagnosis and defect detection of GIS switch-gear, insulators, wires, fittings, etc. [1-2].

Due to the high X-ray energy, it has certain damage to the human body, and it also brings certain inconvenience in the process of equipment detection [3-4]. In contrast, terahertz technology has low emission energy and can detect substances with low density, which to some extent compensates for substances that X-rays cannot detect.

The typical pulse width of the terahertz pulse is on the order of picoseconds. The signal-to-noise ratio of the radiation intensity measurement can be greater than $10^4$, which is much higher than the Fourier transform infrared spectroscopy technology, which can effectively suppress the interference of background radiation noise, and its stability is better [5-6]. The energy of the terahertz wave photon is only millielectron volts, and the structure of the detected substance is not destroyed by ionization compared with the X-ray. Terahertz pulse sources usually contain only a few cycles of electromagnetic oscillations. The frequency band of a single pulse can cover the range from gigahertz to tens of terahertz, which is convenient for analyzing the spectral properties of matter in a large range [7]. This band covers the pure rotational characteristic spectrum of many gas molecules, and the coherent measurement technology can directly measure the amplitude and phase of the electric field, so it is easy to extract the optical parameters of the sample, such as refractive index and absorption coefficient. Wideband THz-TDS pulse detection simultaneously measures the absorption, determination of chemical composition and concentration of different components in a mixed gas. The characteristic line of the gas can be obtained by comparing the spectrum of the terahertz wave before and after passing through the gas sample. The use of these absorption profiles to detect and identify gases is a good complement to the established mid-infrared spectroscopy. Compared with other band imaging technologies, terahertz imaging technology has a significant increase in resolution and depth of field of the detected image as shown in Figure 2. These unique properties of terahertz play an increasingly important role in gas detection.

![Figure 1. Location of the terahertz wave in the electromagnetic spectrum.](image1)

![Figure 2. The image resolution and depth of field of the terahertz image are significantly improved.](image2)
Nie Hao of China University of Petroleum used the terahertz time-domain spectroscopy system (THz-TDS) device to measure the terahertz spectrum of the air in the gas chamber [8]. The terahertz time-domain spectrum of the experimentally measured different pressure air is shown in Fig. 3. It can be seen from Fig. 3 that under different pressures, the terahertz wave passing through the gas chamber has time delay and amplitude attenuation, and the time delay and amplitude of the gas terahertz time domain spectrum show a regular trend with the decrease of pressure. The time domain signal is calculated to obtain its refractive index in the 0.2~1.5 THz band, as shown in Fig. 4. Figure 4 shows the terahertz refractive index spectrum of the air obtained at a pressure range of $10^{-4}$ to $10^3$ mbar. As can be seen from the figure, as the frequency increases, the refractive index of the air remains substantially unchanged. With the decrease of pressure, the refractive index shows a monotonously decreasing law with strong discriminability. It shows that due to the difference of air pressure, it has different dispersion characteristics, which can distinguish the air of different pressures well. It shows that the time domain spectrum, absorption spectrum and refractive index spectrum obtained by THz-TDS technology can sensitively distinguish vacuum. The change in pressure in the environment shows that terahertz time-domain spectroscopy can be used as a new method to measure the degree of vacuum.

Figure 3. Terahertz time-domain spectrum of air at different pressures.

Figure 4. Terahertz refractive index spectrum of air at different pressures.

Terahertz imaging techniques can be divided into coherent imaging and incoherent imaging. Coherent imaging includes time domain spectral imaging, electro-optic sampling imaging,
Comparison of Continuous Wave Terahertz and Pulse Terahertz Imaging Technology

Principle

(1) Continuous terahertz wave imaging developed earlier, dating back to the 1970s. The earliest continuous terahertz wave imaging system used gas lasers as terahertz sources and bolometers as detectors[11-12]. The principle of continuous wave terahertz imaging is that a continuous wave source provides a higher radiation intensity than a pulse source, which is essentially an intensity imaging. When imaging an object, the scattering effect of the terahertz wave is affected by the defect inside the object or the edge of the damage, which affects the intensity distribution of the terahertz wave electromagnetic field, which is reflected on the terahertz wave image of the object as the brightness and darkness. According to this, the shape, defect or damage position inside the object can be derived.

(2) The basic principle of pulsed terahertz wave imaging is that the terahertz time domain spectroscopy system can obtain the terahertz time domain waveform carrying the sample information after the sample and terahertz wave are applied, and the Fourier transform can be used. The terahertz spectrum of the sample is obtained, so that the intensity and phase information of the sample can be obtained. A two-dimensional electric translation stage is added to the terahertz time-domain spectroscopy system to control the sample to be tested for two-dimensional point-by-point scanning on the focal plane of the terahertz wave. Two-dimensional information of the intensity and phase of the transmitted or reflected terahertz wave is simultaneously recorded. After spectrum analysis, the phase information and amplitude information of each point on the sample at each frequency can be obtained, thereby reconstructing the image of the sample.

System Structure

(1) Complexity: The continuous wave terahertz imaging system uses the Gunn diode oscillator as the radiation source, and the unbiased Schottky diode is used as the detector. The structure is relatively simple and inexpensive; the pulse terahertz wave imaging system requires the price. The more expensive femtosecond laser is used as the light source, and the optical path is complicated, the cost is high, and the volume is generally large.

(2) Transmitting frequency: The continuous wave terahertz emission frequency is low, generally less than 1THz. The terahertz source in the pulse terahertz wave imaging system can emit 0.1~3.0THz or even wider broadband terahertz radiation. High spatial resolution can be achieved by using high frequency terahertz wave imaging.

(3) Resolution: The resolution in an optical system is proportional to the frequency of the light and inversely proportional to the wavelength. It can be seen from (2) that the resolution of the pulse terahertz wave is higher, and the continuous wave terahertz is limited by hardware conditions, and it is difficult to generate a high frequency terahertz wave.

(4) Imaging speed: Continuous wave terahertz has obvious advantages in imaging speed. Due to the difference of terahertz sources, the image data obtained by the two systems are completely different. In a continuous wave system, terahertz wave intensity information is stored only in a matrix form, which can be directly converted into an image. The data of the pulse system is very complicated, so more advanced processing methods are required to make full use of it. Complex data processing makes pulsed terahertz systems take longer to image. Continuous wave terahertz has a variety of detection modes, which is much simpler than the detection of terahertz waves in pulse form, which greatly simplifies the complexity and shortens the time of the terahertz imaging system. Therefore, the terahertz continuous wave imaging system is very suitable for places where imaging accuracy is not very high, but imaging is required in the shortest time.
Conclusion

From the above comparative analysis, it can be concluded that continuous wave terahertz imaging and pulse terahertz imaging technology have their own advantages and disadvantages. However, for vacuum-charged detection, pulsed terahertz imaging is expensive, unstable, and susceptible to disturbances such as on-site noise, which affects the experimental results. Continuous wave terahertz imaging technology has higher radiant power, lower price and faster imaging speed. Moreover, when applied to the actual situation on site, the on-site operation is convenient, the carrying is convenient, the test is more stable, and has higher practical value.

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