Mode Transition of Trichel pulses

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Abstract. The trichel pulse is a typical kind of negative corona current observed in electronegative gases. In this work, stochastic behavior of the trichel pulse has been investigated. The experiment is performed in a negative corona reactor consisting of a stainless steel pin and a stainless steel powered by a dc high voltage source. The characteristic parameters distributions of corona current pulses, including the amplitude, rise time, half-wave time, and repetition frequency, are analyzed statistically. The results show there is a mode transition during the period of voltage increasing. This transition process happens in a certain voltage region, and change of pulse amplitude is the main difference between the two modes.

1. Introduction
In recent years, the corona discharge presented wide application such as material modification, chemical, electrostatic precipitators and so on. Then, more and more efforts to research on the corona discharge were shown in the related literatures. The corona discharge is usually produced in a strong distortion field by all kinds of discharge electrode structure which has the different characteristics. Trichel pulse is a typical kind of negative corona current which was first observed by Trichel in 1934 with a pulsating current mode in electronegative gases and named after him [1]. This kind of corona current consists of a train of pulses with very regular forms, short rise time and durations, and long intervals.

In the past two and half decades both experimental methods and numerical simulation approaches were used to study the characteristics of corona currents. For example, Loeb et al. stated that the Trichel pulses existed only in the electronegative gases [2-3]. They also presented a theory of successive electro avalanches, each giving rise to three successors near the end of its development to explain the characteristics of trichel pulse. Lama et al commented that the charge per pulse of the current was only dependent on the radius of the point electrode but independent of the voltage as well as the gap length [4]. Trinh et al reported that the amplitude of the pulse reduces with the increase of the applied voltage [5-7].

Most of the aforementioned researches were all concentrated on the current-voltage characteristic of Trichel pulses, without investigating the specific characteristics of the pulse including the repetition frequency, the amplitude, the rise time, and the duration of the pulses. In consideration of the randomness of trichel pulse, the relationship between the detailed characteristics of Trichel pulses mentioned above and the discharge condition calls for further was investigated in the paper.

A novel needle-to-plate electrode structure was designed to study the detailed characteristics of Trichel pulses mentioned above. Using the statistical methods, all the detailed characteristics of Trichel pulses mentioned above are analyzed. The results reveal the mutation of the amplitude with the
voltage increasing, which can more clearly defined the different modes of Trichel pulse during the process of negative corona discharge developing, and it is significant for the future research about trichel pulse.

2. Experimental setup
The experimental setup is designed for needle-plate trichel pulse tests, as shown in Figure 1. A needle electrode with a curvature radius of 0.15mm is used as the negative electrode, and connected to a negative dc power supply. A plane with a size of 50mm × 100mm and a thickness of 1mm is used as ground electrode and connected with a sampling resistor of 2 kΩ. The needle is located with a horizontal distance of 17mm from the plane electrode. A DC generator supplied high voltage for discharges with a continuous regulation ranged from 0 to -20kv. The voltage between the needle and the round is measured by a DOP2024 type oscilloscope. Meanwhile the current in the circuit can be measured by measuring the voltage on the sampling resistor. All experiments are carried up in ambient air at room temperature without external airflow.

3. Characteristics of trichel pulses
A trichel pulse current measured by a sampling resistor is provided in Figure 2. The typical parameters for the trichel pulse, including pulse amplitude A, pulse rise time tr, and pulse half-wave time tf are also schematically shown in this figure.

Figure 1. Schematic of the experimental setting

Figure 2. Trichel pulse current measured by a sampling resistor
The applied negative voltage on the needle directly causes a classic trichel corona discharge. On condition that the distance between the needle and the plate is 17 mm, the sampling resistor was 2 KΩ, and the applied voltage of the power supply is ranged from 6000–8000 V, the trichel pulse discharges are performed. Figure 3 (a)-(d) show the discharge voltage waveforms of the test resistor at different external power-supply voltages. The total record time is 1 ms.

From the figure, it can be found that the discharge voltage waveforms are the typical trichel pulses as well as corona discharges. At the applied power voltage, DC current component does not begin to exist in the Trichel pulses. Compared to Li’s works [8], this is mainly due to the applied voltage range just from 6000–8000 V. Since DC discharge waveform is the characteristic of the glow discharge, it means that the provided discharge are still trichel pulses now.

At the applied voltage of 6500 V, the pulse currents with the amplitude of about 0.2 mA always occur. With the applied voltage increasing, the interval time between pulses obviously decreases while more little amplitude pulses obviously appear. At the applied voltage of 8000 V, the trichel pulse current is reduced and kept with about 0.1 mA level.

![Figure 3](image-url)

Figure 3. Trichel discharge current waveforms stored in the oscilloscope with different applied voltages.

The characteristics of trichel pulses in a single point-to-plane configuration have been demonstrated. The amplitude and the interval time of these pulses are not generally constant and always fluctuate in time. Since these fluctuations are subject to a certain probability distribution, the statistical processing is used for the analysis of the pulse fluctuations.

All the measured pulses under different applied voltages are used to analyze the probability density distribution of the amplitude. As shown in Figure 4, the amplitude of trichel pulses obeys a normal distribution. Since the pulse amplitude obeys a normal distribution, the probability density function $P(A)$ can be defined as,

$$P(A) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(A-\mu)^2}{2\sigma^2}}$$  \hspace{1cm} (1.1)
where \( \mu \) and \( \sigma \) are the mean and variance of corona pulse amplitudes, respectively.

### Table 1. The mean and the variance of four pulse parameters

|                          | 6.5kv | 7kv  | 7.5kv | 8kv  |
|--------------------------|-------|------|-------|------|
| **The rising time**      |       |      |       |      |
| Mean(s)                  | 7.9e-8| 7.8e-8| 7.5e-8| 7.2e-8|
| Variance(s\(^2\))        | 8.5e-9| 7.9e-9| 1.0e-8| 8.1e-9|
| Maximum of probability density (s) | 7.8e-8| 7.75e-8| 7.47e-8| 7.1e-8|
| **The half-wave time**   |       |      |       |      |
| Mean(s)                  | 1.94e-7| 2.00e-7| 1.88e-7| 1.90e-7|
| Variance(s\(^2\))        | 6.00e-8| 7.35e-8| 3.97e-8| 5.78e-8|
| Maximum of probability density(s) | 1.95e-7| 1.94e-7| 1.90e-7| 1.89e-7|
| **The amplitude**        |       |      |       |      |
| Mean(mA)                 | -0.2465| -0.2259| -0.1922| -0.1620|
| Variance(mA\(^2\))       | 0.0271  | 0.0416| 0.0410| 0.0282|
| Maximum of probability density(mA) | -0.23| -0.22| -0.15| -0.16|
| **The interval**         |       |      |       |      |
| Mean(s)                  | 2.86e-5| 1.75e-5| 1.02e-5| 6.26e-6|
| Variance(s\(^2\))        | 3.46e-6| 5.88e-5| 4.32e-5| 2.88e-6|
| Maximum of probability density(s) | 2.89e-5| 1.98e-5| 8.92e-6| 6.18e-6|

![Graphs](a). the rise time  
![Graphs](b). the half-wave time
According to the Table 1 and Figure 4, As the voltage increase, the rising time and falling time change a little as shown. Both rising time and falling time slight reduce as the voltage increase, this characteristic can be seen both in Table 1 and Figure 4a-4b. The rising time is all between 70~80ns, and the falling time is around 180~200ns. When voltage is 6.5kv, there is only one peak in the waveform, which means there is one regime of pulse amplitude, this regime current is about -0.25mA, consistency as Table 1. However, when voltage is 7kv or 7.5kv, there are two regimes of pulse amplitude. As the voltage increasing from 7kv to 7.5kv, the bigger regime transfer from -0.25mA to -0.15mA. As in Table 1, the mean of pulse amplitude is -0.2259 at the voltage 7kv while -0.19 at voltage 7.5kv. according to Figure 4c, it suggest that when voltage is around 7kv or 7.5kv, the amplitude of pulse has both large amplitude and small amplitude, as the voltage increasing, the large amplitude pulse become fewer as the small amplitude pulse become more.

Figure 4d shows the probability distribution of the pulse interval, as the same as Figure 4c, when voltage is 7kv and 7.5kv, there is two regime, contrast to Fig.4c, we suggest that the smaller interval is between smaller pulse.

4. Discussion
According to the results, we believe that during the period of voltage increasing, there are different modes of trichel pulse appeared, in this paper, when voltage is below 6.5kv, we make it mode A, the characteristic of this mode is that the amplitude is bigger, the corona discharge current is more than -0.2mA, and the interval of pulse is all more than 10us. When the voltage is bigger than 8kv, we call it mode B, the characteristic of this mode is small amplitude, high frequency.

According to the previous work [9-11], Trichel pulse is usually attributed to the release of accumulated energy, which depends on the negative ions in the space. When the applied voltage is low, the diffusion motion is responsible for the release of negative ions in the space. As the voltage increases, the negative ions propagate from the negative electrode to the grounded electrode in the electrical field. At this moment, instead of diffusion motion, the release of charges from grounded electrode becomes the main cause. Consequently, the pulse interval increases with the decrease of voltage. Meanwhile, the corresponding energy of one pulse also reduces. That is to say, the change of release method of negative ions in the space results in the mode conversion.

5. Conclusion
In this letter, mode characteristics of needle-to-plate trichel pulse discharge are studied. The experimental results indicate that with the applied voltage increasing, the interval time between pulses obviously decreases while more little amplitude pulses obviously appear. The statistical analysis showed that there is a mutation during the change process of pulses amplitude, this change happened in a increasing zone of the voltage which is 7000V to 7500V under this experimental condition. The mode of trichel pulse discharge has obviously changed as amplitude changing which can be used as mode identification foundation.

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