Electrode Structure Effects on Electrostatic Spray System Efficiency for Bladeless Wind Power Generation

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Abstract. The liquid medium can be atomized into small droplets and then it moves towards the reverse direction of the electric field force under the wind action, which can increase overall electrical potential energy of the system and realize the conversion of wind energy to the electric energy. In this paper, multi injection needle mesh electrode is taken in the electrostatic wind power generation system as the research object. Based on the ANSYS simulation platform, electric field distribution and the influence of electric field intensity on spray effect at injection needle in different structure like quadrangular, rhombic, circular and hexagonal high pressure electrodes are studied. The results show that the voltage level of discharge terminal in circular electrode structure is significantly higher than that of the other electrode structures and voltage level is needed for multiple jets significantly lower than the other electrode structures.

1. Introduction

The bladeless wind power generation system [1] is based on the principle of electrostatic conversion [2], which is mainly composed of electrostatic atomizing electrode, electrostatic atomizing injection needle and charge collection device. The system structure is shown in figure 1.

Figure 1. Principle of bladeless wind power generation system

As shown in figure 1, injection needle is located at the center of the electrode and electrostatic field is produced if the electrode’s potential is on a high level. The liquid medium is subjected to combine effect of gravity, surface tension and electric field force in the injection pipe. The "solid-liquid"
interface is formed double electrical layer. When the liquid medium is separated from the injection needle, electric charge separation of electrical double layer is made the droplet charged [2]. When surface tension of droplet is balanced with charge repulsion generated by the electrostatic stress, droplet will not be atomized. When the charge of droplet is exceeded Rayleigh limit (Qmax), droplets will be broken into small charged particles. After charged droplets atomization can overcome the effect of electric field force and move to the charge collection device to generate a ground current which completes the conversion of wind energy to electrical energy [3].

According to above analysis, liquid in the spray needle is charged through inductive charging method. The electric field intensity at injection needle will directly affect the amount of liquid charge [4]. At the same time, according to the limit of Bates theory [5], maximum power utilization of wind power $P_{\text{max}}$ can be expressed as equation (1):

$$P_{\text{max}} = \frac{8}{27} A \rho_a V_1^3$$

Here, $A$ is the area of net electrode, $\rho_a$ is air density and $V_1$ is the wind speed when wind is not in contact with net electrode structure. The net electrode structure can be obtained a more effective sweep area under natural wind conditions. Based on this consideration, different electrode shapes like circular, diamond, quadrilateral and hexagonal are chosen as the research object.

### 2 Electric field distribution of injection needle

#### 2.1 Electric field distribution of single electrode

The electric field distribution of circular, quadrilateral, rhombic and hexagonal electrodes are simulated and analyzed on the ANSYS software platform [6]. The parameters are as follows: diameter of the inner tangential circle is 24 mm, electrode setting voltage is 5 KV, air dielectric constant is 1 and air model with 20 cm long and 20 cm width. The structure of different electrode shapes are compared and analyzed and the result is shown in figure 2.

As shown in figure 2, electric field intensity of the quadrangular electrode is $E_{\text{min}}=0.328 \times 10^{-8}$, $E_{\text{max}}=0.104 \times 10^{5}$; electric field intensity of the hexagonal electrode is $E_{\text{min}}=0.327 \times 10^{8}$, $E_{\text{max}}=0.443 \times 10^{6}$.
diamond electric field is mainly distributed at the four tip angles and electric field intensity rest of the part is small, in which $E_{\text{min}}=0.328 \times 10^{-8}$ and $E_{\text{max}}=0.104 \times 10^{-5}$ are similar to the distribution of quadrangular electrode electric field. The electric field force vector lines distribution of above three structures is not uniform. In comparison, distribution of the electric field force vector line of circular electrode is more uniform, in which the electric field intensity is $E_{\text{min}}=0.209 \times 10^{-8}$, $E_{\text{max}}=0.325 \times 10^{-6}$ and there is no tip around it. It can resist high potential and it is not easy to spark.

2.2 Electric field distribution structure of electrode spray needle
The liquid is induced to form dielectric layer and split at the end of the injection needle, so electric field intensity at the injection needle will directly affect the droplet induction [7]. To find out the influence of electrode structure on electrostatic atomization in practical application, a model of electrode spray needle is built and its electric field distribution is studied on ANSYS software platform. The external diameter of injection needle is 0.06 mm, the inner diameter is 0.03 mm and electrode voltage is 5 KV. The electric field intensity vector and induction voltage at injection needle under different electrode structures can be calculated respectively, as shown in figure 3.

![Figure 3](image1)

(a) Quadrilateral (b) Diamond
(c) Circular (d) Hexagon

Figure 3. Electric field distribution under different electrode configurations

According to figure 3, under the same conditions, induced electric field intensity by the needle in circular electrode is the largest ($E_{\text{max}}=0.926 \times 10^{7}$), followed by the quadrilateral electrode. The conclusion is consistent with the electric field intensity of four electrodes without injection. Figure 4 is the simulation results of the induced voltage in four structures.

As shown in figure 4, red part is represented the electrode voltage and the dark blue part is represented the needle induced voltage. In four structures, induction voltage of hexagonal injection needle is the largest and tip discharging is easier to occur. Induction voltage of the diamond is the smallest and voltage is mainly concentrated in four angles; the plane of circular electrode is smooth, distribution of the voltage is more uniform and it is not easy to form tip discharging in the circular electrode injection needle.
2.3 Electric field distribution of multi-spray needle mesh electrode

Based on the above analysis, considering high wind power generation system requirements, multiple needles are needed to work simultaneously. To further study of the multiple electrodes interaction, different structure of electric field distribution like quadrangular, circular, hexagonal and diamond reticulated electrodes are studied. The free grid partition model of the electrode structures are shown in figure 5.

Structural parameters of the mesh electrode are set as: length is 101 mm, width is 101 mm and thickness is 1 mm; Inner tangent circle diameter of circular, diamond, hexagonal and quadrangular electrodes all are 24 mm; electrode setting voltage is 5 KV; air dielectric constant is set to 1; resistance coefficient is set to $R_X = 71 \ \Omega \text{m}$ with brass material, air rectangular model is added that has the size of 20 cm*20 cm. Based on the above parameters, free meshing technology are used for four electrode models to obtain higher accuracy. After mesh is divided, 5 KV load voltage is applied to the model plane and finite element analysis (FEA) method is used to calculate. The results are shown in figure 6.
Figure 6. Electric field force vector simulation diagram

As shown in figure 6(a), red line is represented the strongest electric field and the blue line is represented the weakest electric field intensity. In the circular electrode, $E_{\text{min}}=0.213\times10^{-9}$, $E_{\text{max}}=0.299\times10^{-6}$, the difference between maximum electric field intensity and average electric field intensity are very small. That means distribution of electric field force lines around the circle is more uniform. It is relatively uniform in the largest electric field intensity and does not cluster together so that the phenomenon of tip discharging can be avoided with the increase of voltage. From figure 6(b), distribution of electric field lines around the diamond is extremely uneven. The electric field lines are basically concentrated at the tip. Electric field lines with weak electric field intensity is scattered on the smooth surface and $E_{\text{min}}=0.138\times10^{-5}$, $E_{\text{max}}=0.210\times10^{-9}$, maximum electric field intensity and average electric field intensity are different, so it is easy to ionize by using this type of electrode structure, which is dangerous in practical application. For quadrilateral electrode, as shown in figure 6(c), distribution of electric field lines is more uniform. Most of the electric field distribution is green electric field. The distribution of red line electric field intensity is short; electric field lines between electrodes to electrode are greatly influenced. The direction of surrounded electric field lines is outward but the electric field lines between each other are inward expansion and electrode is interfered with each other.

As the above analysis, distribution of circular electrode electric field lines is more uniform, and regional function of the maximum electric field intensity is much larger than two other kinds. Maximum electric field intensity is little different from the average electric field and it is easy to avoid ionization discharge. It is more suitable to be used in the electrostatic atomizing wind power generation system with multi injection needle.

3 Experimental setup

An experimental system is built to verify the simulation results. The system model is shown in figure 7.
Figure 7. Experimental device for electrostatic atomization

As shown in figure 7, electrostatic atomization system of bladeless electrostatic wind power generation is composed of nozzle, electrode and DC high voltage power supply. The electric field is generated near the nozzle after the electrode is connected to DC high voltage power supply and liquid drops can be atomized when it is separated with the nozzle and produced electric field by the electrode. Liquid flow rate can be adjusted by controlling linear module’s propulsion speed using the stepper motor. Different shapes of electrodes can be placed on the electrode plate for droplets atomization experiment. The voltage is fixed at 5 KV, liquid flow velocity is 1.35 ml/s, liquid medium is water, external diameter of the injection needle is 0.06 mm, inner diameter is 0.003 mm and current in the injection needle is tested by high precision micro-ammeter in the experiment. The average current value is generated by the circular electrode, quadrangular electrode, diamond electrode and the hexagonal electrode in the atomization which are recorded respectively for every ten seconds, the results are shown in figure 8.

Figure 8. Ground current of needle under different electrodes shape

As shown in figure 8, under the same conditions, induced needle current is the largest in circular electrode followed by the quadrilateral and experimental data are consistent with the simulation results. In the four electrode structures, circular electrode can be achieved better atomization effect.

4 Conclusion
Through the analysis of electric field distribution and electric field intensity of four kinds of electrode structures with circular, quadrangular, diamond and hexagons it is shown that the distribution of the electric field force vector lines is not uniform and electric field force vector lines are unevenly distributed because of the existence of sharp angle on quadrangle, diamond and hexagon electrodes. The circular electrode surface is smooth and the voltage is uniformly distributed. Also, electric potential induction of injection needle is the highest and electrostatic discharge can be avoided easily.
The largest current can be obtained during the electrostatic atomization process. So, the circular electrode structure is more suitable for the electrostatic atomization system.

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