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Retraction

Retracted: Numerical Simulation and Active Protection of Lightning Discharge Based on Quantum Heuristic Evolutionary Algorithm

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] M. Wu, Y. Qian, and C. Yang, "Numerical Simulation and Active Protection of Lightning Discharge Based on Quantum Heuristic Evolutionary Algorithm," *International Transactions on Electrical Energy Systems*, vol. 2022, Article ID 4945545, 15 pages, 2022.

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Research Article

Numerical Simulation and Active Protection of Lightning Discharge Based on Quantum Heuristic Evolutionary Algorithm

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Thunder is a discharge phenomenon that often occurs in nature. Due to its physical influences such as strong current, high temperature, strong shock waves, and strong electromagnetic radiation, it has a huge destructive effect instantly, which may bring serious threats to people's lives and property safety. This study aimed to study the lightning discharge numerical simulation and active protection based on the quantum heuristic evolutionary algorithm and proposed to apply the lightning discharge numerical simulation to the prevention of lightning disasters. This article gives a detailed description of the quantum algorithm, the generation, and harm of lightning discharge. The genetic algorithm is used to optimize the lightning data simulation algorithm, and the optimization process is introduced in detail. In addition, this article conducts related experiments on lightning discharge numerical simulation and active protection. The experimental results show that targeted active protection and effective numerical simulation are important measures to prevent lightning disasters. Active lightning protection measures can reduce lightning by 30%. Losses are caused by disasters.

1. Introduction

Thunder is a special meteorological phenomenon. It is recognized by the United Nations as one of the ten most serious natural disasters. According to the International Electrical Standards Conference, thunder and lightning are called "the main public hazard in the electronic age." Every day, there are about 8 million lightning strikes in the world. The voltage of each lightning is as high as 100 million to 1 billion volts, and the current intensity is as high as 20,000 to 40,000 amperes. Things produced by high voltage, high current, strong electromagnetic radiation, and lightning often cause serious disasters and economic losses. In particular, due to the large-scale adoption of microelectronic equipment, lightning disasters have become more and more serious, and the impact has become more and more serious. Social surveillance and protection of lightning strikes have also been strengthened. It is particularly important to study lightning discharge and its numerical simulation, as well as related protection countermeasures under lightning transients.

Until now, mankind has not found an effective way to prevent thunder and lightning. Elimination of lightning strikes can avoid loss of life and property and minimize the damage of lightning. If a service facility such as a building is struck by lightning, the people in the building, the building itself, the objects and equipment inside, and the service facilities connected to it may be in danger, and even collective casualties and huge property losses may occur. The direct economic loss and its negative impact will have a bad impact on the society. Therefore, lightning protection measures must be taken to reduce the disasters and losses caused by lightning strikes. In addition to the lightning protection required by the protection object, to reduce economic losses, lightning protection countermeasures are also necessary and reasonable. After years of scientific analysis and practical experience, the sum of the losses that still exist after adopting lightning protection measures and the costs of the adopted protection measures are far less than the losses caused by no measures. Therefore, in terms of economic rationality, adopting measures are necessary and reasonable. As a new intelligent optimization algorithm, the quantum evolutionary algorithm has excellent diversity characteristics and is suitable for parallel computing. Compared with traditional optimization algorithms, quantum evolutionary algorithms have the characteristics of balanced search and development, fast convergence, and high global optimization performance. The development of quantum theory is changing with each passing day. With the combination of more quantum theory knowledge and traditional evolutionary technology, the development prospects of quantum evolutionary algorithm in lightning discharge research and protection are getting broader.

In recent years, people's research on quantum algorithms, lightning numerical simulation, and protection has continued to deepen. In the related research on quantum algorithms, Zhou proposed an effective coevolutionary quantum algorithm (ECQA) for the traditional quantum evolutionary algorithm that is difficult to find the global optimal solution in the multimodal optimization problem. The ECQA combines cooperative evolution and adaptive mutation strategies, which can independently complete the evolution process and effectively exchange evolution information [1]. To improve the performance of traditional quantum-inspired evolutionary algorithms, Ming S proposed a novel quantum-inspired coevolutionary algorithm (NQCEA) in his research. Experiments show that NQCEA has better performance and can simulate lightning current better [2]. In the research on the application of quantum algorithms, Lin-line proposed a wireless sensor network target coverage method based on quantum ant colony evolution algorithm (QACEA) for the coverage of self-organizing wireless sensor networks. This method introduces the quantum state vector into the coding of the ant colony algorithm and realizes the dynamic adjustment of the ant colony through the quantum rotating port [3]. Hui has different applicability for conventional prediction methods of subgrade settlement using observation data, and the prediction results fluctuate greatly and the accuracy is low. A method based on least-squares support vector regression and real number coding quantum evolution algorithm is proposed [4]. Zhang H said that in recent years, swarm intelligence algorithms such as genetic algorithm and particle swarm optimization have provided new ways to solve complex batch problems, but they are prone to local optima. To fill this gap and obtain the global optimal solution, the quantum algorithm is integrated into the classical evolutionary genetic algorithm in his research [5]. In the study of lightning numerical simulation, Baranovskiy studied the heating phenomenon of deciduous tree trunks under the influence of cloud and lightning discharge current. The heat radiation through the tree trunk during the passage of the discharge current is described by the Joule–Lenz law [6]. In the lightning protection research, Rong researched and summarized the latest developments in lightning protection from the aspects of lightning positioning and observation, lightning physics, lightning electromagnetic transients, and lightning protection of various systems [7]. In the research of these researchers, most of them are based on the existing methods, and the innovation of research methods is insufficient in the research process.

The innovation of this article lies in the research on quantum algorithms, lightning protection, and so on. Through related research on the calculation process of quantum heuristic evolution algorithm, quantum coding, and other issues, the research results are applied to the application of numerical simulation of lightning discharge, and the numerical simulation of lightning discharge provides some for the active protection of lightning more targeted measures.

2. Simulation Numerical Value and Active Protection of Lightning Discharge Based on Evolutionary Algorithm

2.1. Generation, Harm, and Prevention of Lightning Discharge

2.1.1. Generation of Lightning Discharge. Thunder and lightning are electrical discharges that occur between lightning clouds or between clouds and the ground. Thunder cloud is the mature stage of convective cloud development, and it often develops in cumulus cloud [8]. The condition for generating lightning is the accumulation and the formation of polarity in the thunderstorm cloud. According to different terrain and meteorological conditions, lightning can be generally divided into three categories: thermal lightning, front lightning (hot front lightning and cold front lightning), and terrain lightning.

(1) The Discharge Process of Lightning. The upper, middle, and lower parts of thunderclouds gather electric charges with different polarities. When the electric charges of these charges with different polarities accumulate to a certain value, an electric field is generated between the cloud and the cloud cluster and the ground. When the electric field intensity reaches when the air destroys the intensity, a discharge phenomenon between positive and negative charges occurs. The intense spark discharge at this moment is lightning [9]. Figure 1 shows three possible lightning strikes in a lightning strike.

2.1.2. Description of Lightning Current

*(1) Waveform of Lightning Current.*Figure 2 shows a schematic diagram of lightning waveforms.

As shown in Figure 2, first, starting from the three scales of 0.1, 0.9, and 1.0 of the current on the vertical axis, three vertical lines are drawn perpendicular to the current on the vertical axis. The first two vertical lines intersect the head of the wavy curve. a and b are used to connect the line created between a and b. The straight lines c and d are the points obtained by crossing the third vertical line drawn at a scale of 1.0 on the overcurrent vertical axis and the time horizontal axis. The time between vertical foot point e and point d is

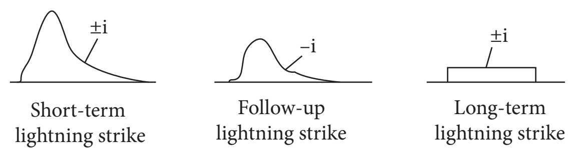

Figure 1: Three possible lightning strikes in a flash strike.

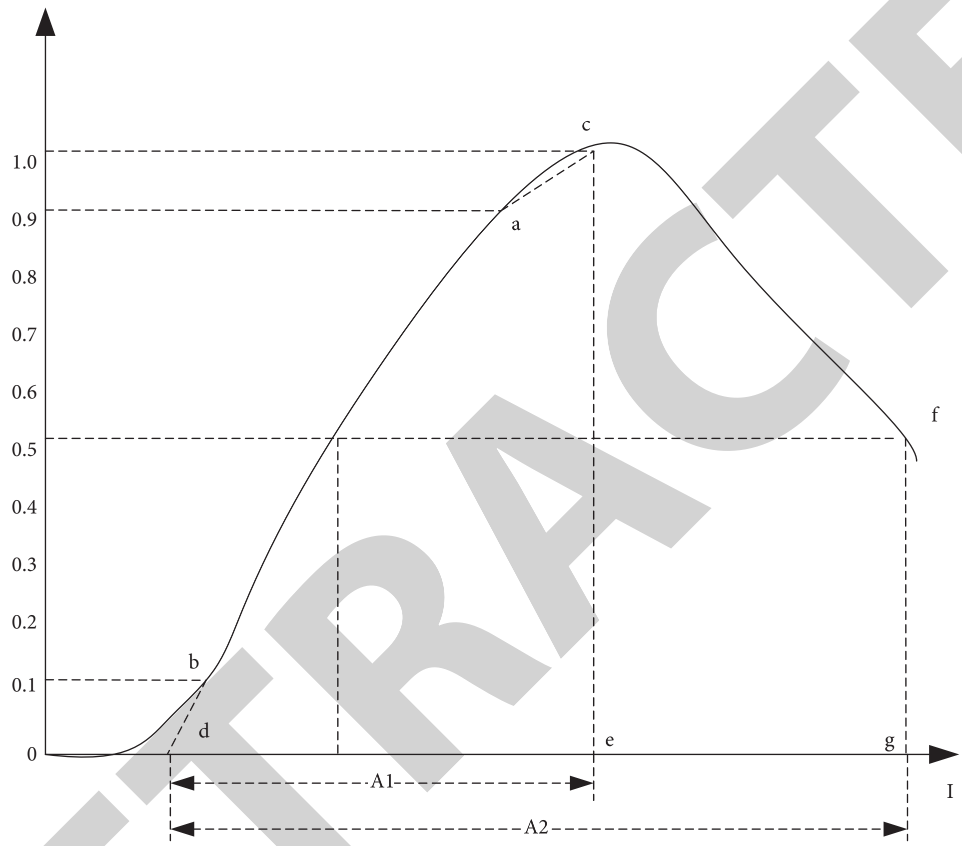

Figure 2: Lightning waveform.

defined as the wave front time and is represented by A1. Next, the vertical line of the vertical axis is denoted by A1. The current is drawn from the 0.5 scale of the vertical axis of the current and the line of the wavy curve and the tail part of the wave are intersected by point *f*, and a vertical line is drawn from point F to the horizontal axis of time. Point *g* and point *d* are defined as the wavelength time represented by A2.

(2) The Amplitude of Lightning Current. In a lightning strike, the amplitude of the lightning current generated by each discharge is different. Among them, the lightning current that generates positive lightning is relatively large. The current observation record maximum value is 430 kA, but the probability of generating positive lightning is very low, and the lightning current that generates negative lightning is not large. Because of the positive lightning, it usually does not exceed 200 kA. However, the probability of a negative lightning is much higher than the probability of a positive lightning [10]. Tables 1, 2, and 3 show the range those different types of lightning protection structures should be able to withstand in the lightning protection design process. The first type, the second type, and the third type of lightning protection buildings are the lightning protection grades of buildings according to GB 50057–2010 "Lightning Protection Design Code for Buildings."

2.1.3. The Destructive Effect of Lightning Current. The destructive effects of lightning are mainly caused by lightning currents. Generally speaking, the danger caused by thunder is divided into three types. One is the impact of direct lightning; that is, lightning directly affects buildings or equipment. The second is the secondary effect of lightning, that is, electrostatic induction and electromagnetic induction caused by lightning current. The third is the effect of spherical mine [11].

(1) The Thermal Effect of Lightning Current and Its Harm. If the lightning current of lightning strikes an object moves, it will generate heat. According to Joule's law, the heat released by lightning current is as follows:

Table 1: Lightning current amplitude of the first lightning strike.

Lightning current parameters	Lightning protection building category		
	One type	Second category	Three categories
I amplitude	220	180	120
Current waveform (μs)	20/350	20/350	20/350

Table 2: Amplitude of lightning current after the first lightning strike.

Lightning current parameters	Lightning protection building category		
	One type	Second category	Three categories
I amplitude	60	45	30
Current waveform (μs)	0.5/100	0.5/100	0.5/100

Table 3: Lightning current amplitude of long-term lightning strike.

Lightning current parameters	Lightning protection building category		
	One type	Second category	Three categories
Q1 charge (C)	220	180	120
T time (s)	0.5	0.5	0.5

$$R = \int_0^t i^2 M dt, \tag{1}$$

where R represents heat, i represents lightning current, and M represents the resistance of the lightning channel. The temperature rise caused by the lightning current of the lightning channel is as follows:

$$\Delta t = \frac{R}{mc}, \tag{2}$$

where m represents the mass of the object through which lightning current flows, and c represents the specific heat capacity of the object through which lightning current flows. Due to the thermal effect of lightning current, it is easy to cause the melting of dry grass, trees, and metals. If the joints of long metal pipelines such as oil pipelines, gas pipelines, and chemical liquid pipelines are not well connected, the poor connection will become hot or melted due to severe thermal effects, which may cause a fire accident. These are destructive effects due to the thermal effects of lightning currents. Generally speaking, when the thickness of the steel plate of a metal can exceed 4 mm, it can be directly resistant to lightning strikes and can be directly used to receive lightning.

2.1.4. Lightning Damage. Lightning strikes caused by lightning have the characteristics of large current, short time, high frequency, and high voltage. It has electric effect, thermal effect, mechanical effect, electrostatic induction, electromagnetic induction, lightning intrusion wave, and high-voltage counterattack effect on lightning protection devices of buildings [5]. Thunder has great destructive power. It will not only cause damage to people, animals, trees, and buildings, various industrial facilities, and agricultural facilities but also cause fires and explosions. The danger of thunder is generally divided into two categories. One is the thermal and electrodynamic effects of direct thunder on people and buildings. The damage of lightning to the human body has the direct effect of current, the effect of overpressure or power, and the effect of high temperature. When a person is struck by lightning, the current quickly passes through the human body. In severe cases, the heartbeat and breathing may stop, and the brain tissue will be deprived of oxygen and die. The other is the secondary effect of lightning, that is, electrostatic induction and electromagnetic induction caused by lightning current [12, 13]. Figure 3 is a schematic diagram of part of the damage caused by lightning.

2.1.5. Active Protection against Lightning. Lightning protection is to introduce the energy of lightning current into the ground as much as possible through reasonable and effective safe discharge methods [14]. The danger of lightning strikes includes the danger of direct lightning strikes and the danger of inductive lightning strikes. Therefore, a complete lightning strike protection system must include protection from direct lightning strikes (external lightning strike protection) and protection against inductive lightning strikes (internal lightning strike protection) [15]. Nowadays, the importance, urgency, and complexity of lightning protection work have greatly increased. Therefore, to improve the lightning protection of mankind, it is necessary to take a responsible attitude towards the country and the people and timely research, learn, and apply the latest lightning protection technology to reduce the disasters caused by lightning [16, 17]. Figure 4 is a diagram of the lightning protection system.

2.2. Quantum Heuristic Evolutionary Algorithm. At this stage, the heuristic algorithm is mainly based on the natural body algorithm, mainly including ant colony algorithm, simulated annealing method, and neural network. At this stage, the heuristic algorithm is mainly based on the natural

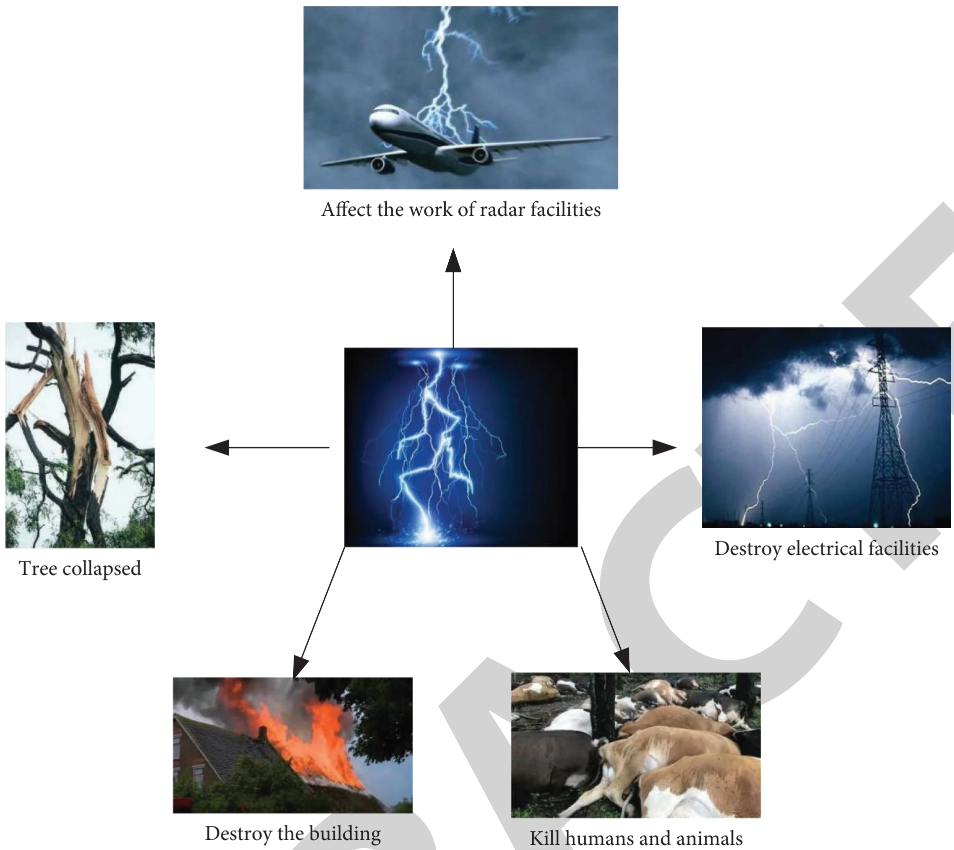

Figure 3: Harm from lightning.

body algorithm, mainly including ant colony algorithm, simulated annealing method, and neural network. Evolutionary algorithm is a self-organization and adaptive artificial intelligence technology, which solves problems by simulating the evolutionary process and mechanism of biology [18]. According to Darwin's theory of natural elimination and Mendel's genetic variation, biological evolution is achieved through replication, mutation, competition, and selection [19]. The original reason that individuals can evolve is to use selection operations. To ensure that the next generation of individuals is not worse than the previous generation, generally better individuals are selected. At the same time, the reorganization operator is used to ensure that new individuals are generated through destructive effects, resulting in better individuals, and more importantly, it can maintain the diversity of the group [20, 21]. When the selection pressure is insufficient, the convergence speed of the algorithm will slow down. If the diversity of individuals is not sufficient, the algorithm will simply be classified as a local optimal algorithm. The genetic algorithm is the most commonly used algorithm in evolutionary algorithms. Figure 5 is a schematic diagram of the genetic algorithm operation process.

2.2.1. Quantum Coding. The quantum chromosome encoding method in the quantum evolution algorithm adopts a new encoding method based on the principle of quantum superposition, that is, quantum encoding. In the concept of queue position, the queue position is expressed as follows: $\begin{bmatrix}\partial \\ \delta\end{bmatrix}$. Among them, ∂^2 and δ^2 represent the probability of taking 0 and 1, respectively, satisfying $\partial^2 + \delta^2 = 1$. The quantum chromosome corresponding to n can be expressed as follows:

$$\begin{bmatrix} \partial_1 & \partial_2 \ldots & \partial_i \ldots & \partial_{n-1} & \partial_n \\ \delta_1 & \delta_2 \ldots & \delta_i \ldots & \delta_{n-1} & \delta_n \end{bmatrix}, \quad i = 1, 2, \ldots n. \tag{3}$$

Among them, ∂_i and δ_i are the probability coefficients of states 0 and 1 in ith state and satisfy $\partial_i + \delta_i = 1$.

2.2.2. Quantum Update. The quantum update operator is the core of the quantum evolutionary algorithm, and its quality directly affects the performance of the algorithm. In the quantum evolution algorithm, because the quantum chromosomes are in the overlapping state and the entangled state, the selection, crossover, and mutation operations of the traditional evolutionary algorithm cannot be used in the update operation [22]. The most basic and most commonly used operation is to use quantum gates to act on each overlapping state, interfering with each other to change the phase, thereby changing the probability of each ground state. The generation of quantum chromosomes of offspring is not determined by the parents' maternal body, but by the probability and state of the most suitable individual for the

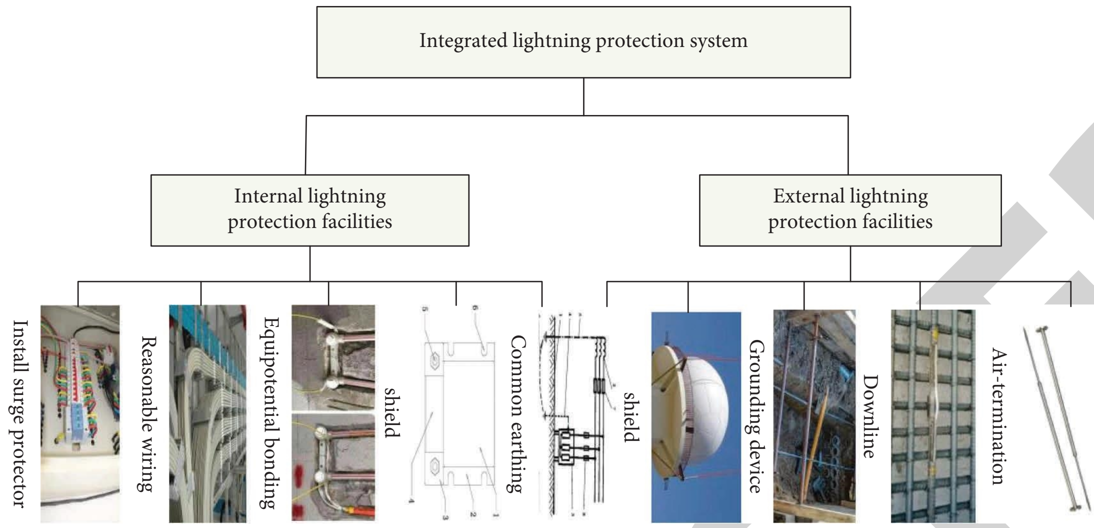

Figure 4: Comprehensive lightning protection system diagrams.

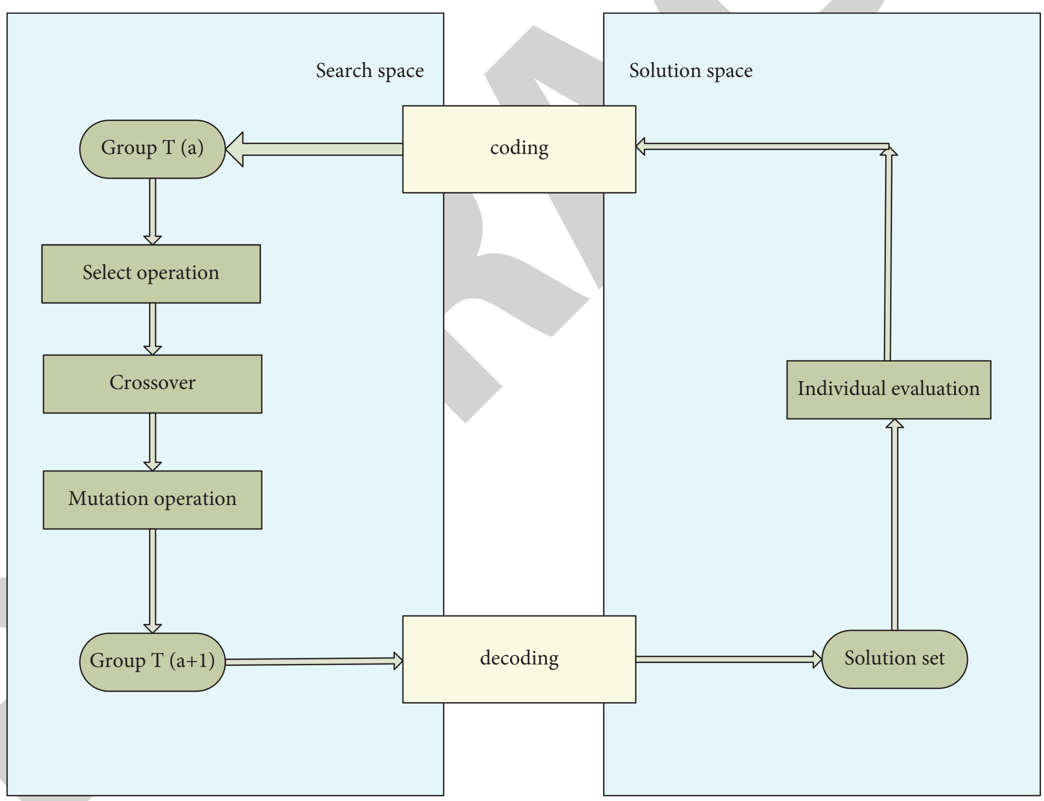

Figure 5: Schematic diagram of the operation process of genetic algorithm.

parents [23]. Therefore, the construction of quantum gates is an important issue for quantum renewal. In addition to the update of the quantum gate, there are other operations such as quantum crossover and quantum sudden mutation [24].

2.2.3. Quantum Gate Update. There are many types of quantum gates. According to the number of qubits running, quantum gates can be divided into 1-bit gates, 2-bit gates, 3-bit gates, and so on. According to the various functions of quantum gates, it can be divided into the following categories: quantum NOT gate N, quantum control NOT gate M, H gate, quantum spin gate X, L gate, etc. Quantum evolutionary algorithms mainly use quantum NOT gate N, quantum spin gate X, and L gate. In the computational model of quantum computing, especially quantum circuits, a quantum gate (quantum gate or quantum logic gate) is a basic quantum circuit that operates a small number of qubits. It is the basis of quantum circuits, just like the relationship between traditional logic gates and ordinary digital circuits.

(1) Quantum NOT Gate N. The quantum NOT gate is a one-bit gate, and its update operation is as follows:

$$\begin{bmatrix} \partial_i' \\ \delta_i' \end{bmatrix} = N * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix} = \begin{bmatrix} \delta_i \\ \partial_i \end{bmatrix}. \tag{4}$$

Among them, $(\partial_i, \delta_i)^t$ and $(\partial_i', \delta_i')^t$ represent the qubits before and after the update, respectively. Therefore, the function of the quantum NOT gate is similar to the mutation operator in the genetic algorithm, exchanging the state and the probability coefficient of the state, thereby preventing immature convergence and providing the algorithm's local search capability.

(2) Quantum Revolving Door X. The quantum spin gate is a 1-bit gate that updates the qubit by changing the phase angle of the qubit. The corresponding calculation is as follows:

$$\begin{bmatrix} \partial_i' \\ \delta_i' \end{bmatrix} = X * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix}. \tag{5}$$

As shown in Figure 6, the quantum spin gate X changes the state of the queue bits by rotating at an angle θ in the polar coordinate diagram.

Among them, $(\partial_i, \delta_i)^t$ represents the state of ith qubit before rotation, and $(\partial_i', \delta_i')^t$ represents the state of ith qubit after rotation. If the angle θ is too large, the evolution time will be earlier and will not converge. If the θ angle is too small, evolution is likely to stagnate.

(3) L Door. The L gate is an improvement of the quantum revolving gate and is defined as follows:

$$\begin{gathered} (\partial_i', \delta_i')^t = L(\partial_i, \delta_i, \theta), \\ (\partial_i'', \delta_i'')^t = X(\theta)(\partial_i, \delta_i)^t. \end{gathered} \tag{6}$$

Among them, $(\partial_i', \delta_i')^t$ represents the state of the qubit after the L gate is updated, and $(\partial_i'', \delta_i'')^t$ represents the state of the qubit after the quantum spin gate is updated. Assuming that a very small number ε is given, which satisfies $0 < \varepsilon < 1$, if $|\partial_i''|^2 \le \varepsilon$ or $|\delta_i''|^2 \ge 1 - \varepsilon$, then

$$(\partial_i', \delta_i')^t = (\sqrt{\varepsilon}, \sqrt{1-\varepsilon})^t. \tag{7}$$

If $|\partial_i''|^2 \ge 1 - \varepsilon$ or $|\delta_i''|^2 \le \varepsilon$, then

$$(\partial_i', \delta_i')^t = (\sqrt{1-\varepsilon}, \sqrt{\varepsilon})^t. \tag{8}$$

In other cases,

$$(\partial_i', \delta_i')^t = (\partial_i'', \delta_i'')^t. \tag{9}$$

It can be seen that the L gate can effectively prevent the algorithm from entering the local optimum.

(4) Quantum-Controlled NOT Gate M. The quantum-controlled NOT gate is a two-bit gate; that is, two qubits can be operated at the same time, and its operation is as follows:

$$\begin{bmatrix} \partial_1' \\ \delta_1' \\ \partial_2' \\ \delta_2' \end{bmatrix} = M * \begin{bmatrix} \partial_1 \\ \delta_1 \\ \partial_2 \\ \delta_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \partial_1 \\ \delta_1 \\ \partial_2 \\ \delta_2 \end{bmatrix} = \begin{bmatrix} \partial_1 \\ \delta_1 \\ \partial_2 \\ \delta_2 \end{bmatrix}. \tag{10}$$

It can be seen from the formula that the quantum-controlled NOT gate actually keeps the first queue bit unchanged and updates the second queue bit.

2.2.4. Algorithm Termination Conditions. There are three main methods for judging whether an evolutionary algorithm terminates: the maximum evolutionary algebra, the algorithm searches for a satisfactory solution, and the algorithm reaches a satisfactory convergence rate. Using quantum chromosome convergence rate, researchers have successively defined the concept of multiple markers of quantum chromosome convergence rate.

(1) The Optimal Group Average Convergence Rate Pr*ob (M (n))>γ*. Assuming that x is the population size, y is the length of the chromosome, and the problem set represented by n is $M(n) = (M_1^n, M_2^n, \ldots M_m^n, \ldots M_x^n)$, the mth binary chromosome is represented as $M_m^n = (b_1^n b_2^n \ldots b_i^n \ldots b_{y-1}^n b_y^n)$, and the corresponding quantum chromosome formula is as follows:

$$\mathrm{Pr}ob(M_m^n) = \prod_{i=1}^{y} P_i. \tag{11}$$

In

$$\begin{gathered} P_i = \begin{cases} |\partial_i|^2, & b_i^n = 0, \\ |\delta_i|^2, & b_i^n = 1, \end{cases} \\ \mathrm{Pr}ob(M(n)) = \frac{1}{x}\sum_{m=1}^{x} \mathrm{Pr}ob(M_m^n). \end{gathered} \tag{12}$$

It can be seen from the above formula that, reflecting the average convergence of all quantum chromosomes, it is also the substantial probability of each qubit. However, the use of this method depends on the binary chromosome of the problem solution. The biggest problem as the termination condition of the algorithm is that γ is not easy to set. Even slight differences in different γ may lead to large differences in computing time [25, 26].

(2) Quantum Chromosome Convergence $C_b(M_m^n)$. Still assuming that the population size is x, the chromosome length is y, and the problem set represented by n is $M(n) = (M_1^n, M_2^n, \ldots M_m^n, \ldots M_x^n)$, the mth binary chromosome is $M_m^n = (b_1^n b_2^n \ldots b_i^n \ldots b_{y-1}^n b_y^n)$, which defines it as follows:

$$C_b(M_m^n) = \frac{1}{y}\sum_{i=1}^{y} \left|1 - 2|\partial_i|^2\right|. \tag{13}$$

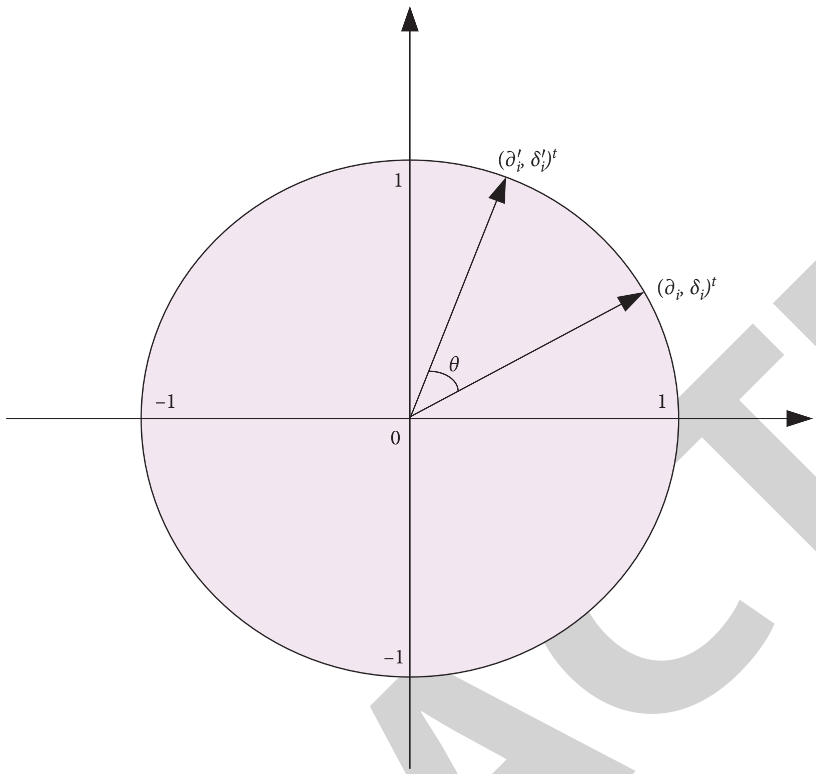

FIGURE 6: Schematic diagrams of the polar coordinates of the quantum rotating gate.

It can be seen that the degree of convergence of quantum chromosome represents the degree of convergence of each qubit of a quantum chromosome and has nothing to do with the solution of the binary problem. Accordingly, the average convergence of the quantum population is defined as:

$$C_{av}(M(n)) = \frac{1}{x}\sum_{m=1}^{x} C_b(M_m^n). \tag{14}$$

The average convergence of the quantum population reflects the convergence of all quantum chromosomes in the entire population, so the judgment condition can be set as follows:

$$C_{av}(M(n)) > \gamma. \tag{15}$$

If you need a faster termination condition, you can also use the maximum convergence of the quantum chromosome as the judgment condition, and the judgment condition is set as follows:

$$C_{\max}(M(n)) > \gamma. \tag{16}$$

If the quantum update uses an L gate instead of a quantum revolving gate, formulas (15) and (16) should be revised as follows:

$$\begin{aligned} C_{av}(M(n)) &> (1-2a)\gamma, \\ C_{\max}(M(n)) &> (1-2a)\gamma. \end{aligned} \tag{17}$$

2.3. Numerical Simulation of Lightning Discharge. The essence of lightning phenomenon is atmospheric discharge. The conditions for the generation of thunder and lightning are the accumulation of thunderclouds and the formation of polarities. Thunder and lightning are generally produced by cumulonimbus clouds that develop with intense convection, so they are often accompanied by strong winds and heavy rain and sometimes hail and tornadoes [27]. The upper part of the cumulonimbus cloud is generally high, up to 20 km, and there are often ice crystals on the upper part of the cloud. The freezing of ice crystals, the destruction of water droplets, the convection of air, etc., generate electric charges in the cloud. The charge distribution in the cloud is more complicated. Generally speaking, the upper part of the cloud is dominated by positive charges, and the lower part is dominated by negative charges. Thunder's voltage is very high, about 100 million to 1 billion volts. Storm clouds usually generate electric charges, with negative charges on the bottom and positive charges on the top, and also generate positive charges on the ground, which follow the cloud like a shadow. Positive and negative charges attract each other, but air is not a good conductor. The power of a strong thunderstorm may reach 10 million watts, which is equivalent to the output power of a small nuclear power plant. During the discharge process, the temperature of the mine road rises sharply, and the air volume expands sharply, producing shock waves and strong thunder. When the electrified thundercloud approaches the ground protruding, violent discharge occurs between them [28]. In the place where thunder falls, there will be strong flashes and explosive roars. This is the lightning and thunder that people see and hear.

The numerical simulation of lightning discharge is easy to understand and analyze because it can visually display, observe, and explain a series of complex phenomena. In addition, numerical simulations can also show physical phenomena that cannot be seen in any experiments that occur within the structure. At the same time, numerical simulation can replace the dangers of explosion accidents, lightning strikes, and effects caused by lightning strikes and carry out some expensive and difficult-to-implement tests.

In modern times, scientists have used air-sounding balloons to detect the vertical electric field distribution in thunderstorm clouds, thereby providing further observational data for scientific research based on the distribution of the charge structure. However, because air-sounding balloons have a certain time lag, they rely on what this method obtains is the distribution of the charge structure in the vertical direction within a time range, and the instantaneous potential distribution at a certain point cannot be obtained, and since multiple lightnings will occur during the detection process of the air probe, the actual situation of the specific lightning potential cannot be obtained, so it is still very difficult to detect thunderstorm clouds with the existing observation technology. Therefore, it is very necessary to use numerical simulation to study the electrification and discharge process in thunderstorm clouds.

2.3.1. Parameterization Scheme of Electrification Process. Based on the different electrification principles of thunderstorm clouds, the charges and polarities of various hydrous particles in thunderstorm clouds are different. The different electrification mechanisms in thunderstorm clouds are the main reason that causes the particles of water in the cloud to carry different positive and negative charges to form different charge structures. Most numerical simulation studies have shown that the charge of thunderclouds mainly comes from induced and noninductive charging. Among them, the noninductive charging mechanism is very sensitive to the ice phase process, especially the second characteristic mode involving the spatial distribution and scale of noninductively charged ice crystal particles, which is closely related to the type of charging process. The inductive electrification mechanism is mainly the charge separation generated when the particles collide and separate from the cloud droplets under the action of the original electric field in the cloud. Based on the research of Mansell et al., the following formula is obtained:

$$\left(\frac{\alpha D_{eg}}{\alpha t}\right)_d = \left(\frac{\pi^3}{8}\right)\left(\frac{6W_g}{\chi(4.5)}\right)E_{gc}E_r Q_{0g}Q_c T_c^2 \cdot \left[\pi\chi(3.5)\beta * \cos\theta\cos E_2 T_g^2 - \frac{\chi(1.5)D_{eg}}{(3Q_g)}\right]. \quad (18)$$

Inductive electrification is under the action of a certain thunderstorm environment electric field, and various hydrological particles of different scales are polarized, so that the upper and lower parts of it induce charges of different polarities. In this mode, the induction electrification is induced by inducing hail and cloud droplets or hail and ice crystals to collide. Based on Ziegler et al.'s collision-induced electrification parameterization, the parameterized equations of inductive electrification between hail and cloud drops or between hail and ice crystals can be given as follows:

$$\left(\frac{\alpha Q_{eg}}{\alpha t}\right)_d = \left(\frac{\pi^3}{8}\right)\left(\frac{6W_g}{\chi(4.5)}\right)E_{gc}E_r N_{0g}N_c T_c^2 \cdot \left[\pi\chi(3.5)\beta * \cos\theta\cos E_2 T_g^2 - \frac{\chi(1.5)Q_{eg}}{(3N_g)}\right]. \quad (19)$$

Among them, Q is the size of the charge carried by the particle, T is the characteristic diameter of the particle, W is the speed of the end of descent, and N is the number concentration.

2.3.2. Discharge Parameterization Scheme. With the in-depth study of thunderstorm cloud-electric activity, people gradually discovered that the lightning team thunderstorm cloud development has an important influence. On the one hand, lightning can limit the upper limit of the electric field intensity generated during the development of thunderstorm clouds. As we all know, after the electric field intensity in the thunderstorm cloud reaches a certain level, a discharge process will occur, and the electric field energy of the internal system of the thunderstorm cloud will be released, thereby inhibiting the recurrence of lightning. The charge intensity of the simulated thundercloud is much higher than the actual situation, so it can only simulate the activity of the thundercloud before the first discharge. The conversion scheme is the basic requirement of the numerical simulation study of thunderstorm cloud-electricity process. Artificial lightning can also be studied to make the occurrence of lightning more controllable.

2.3.3. Initial Mode Setting. The initial calculation formula of the mode and the initial value of the parameters are as follows:

$$\begin{aligned} \partial &= \partial_0(z), \\ \alpha &= \alpha_0(z), \\ \beta &= \beta_0(z) + \Delta\beta, \\ \delta &= \delta_0(z) + \Delta\delta, \\ W &= W_{v0}(z) + \Delta W_{v0}. \end{aligned} \quad (20)$$

There are many studies on the initial excitation of thunderstorms, and the related factors are also complicated. There is no general conclusion yet. The mode can be activated with wet and hot bubbles. In the case of the same layering conditions of the atmosphere, thunderstorms caused by bubbles of high temperature and humidity will become the most severe. The trigger method is to add a damp and heat disturbance field higher than the surrounding environment in the low mode area and use the buoyancy term of the vertical motion equation to establish the initial convection. The perturbation function of the ellipsoid in the form of axial symmetry is adopted in the model:

$$\beta = \beta_0 + \Delta\beta * \cos^2\left(\frac{\pi}{2}\varepsilon\right),$$
$$W_v = W_{v0} + (W_{vn} - W_v)\cos^2\left(\frac{\pi}{2}\varepsilon\right). \tag{21}$$

In the above formula, *xr*, *yr*, and *zr*, respectively, represent the radius of the disturbance zone in several different coordinate directions, $\Delta\beta$ is the maximum disturbance potential temperature at the center, and W_{vn} is the saturation specific humidity after considering the potential temperature disturbance.

3. Numerical Simulation of Lightning Discharge and Active Protection Experiment Based on Quantum Heuristic Evolutionary Algorithm

3.1. The Design of Lightning Discharge Simulation Experiment Scheme. Based on the lightning discharge numerical simulation of the quantum heuristic evolution algorithm, this experiment designed four different lightning discharge simulation experiment schemes. Table 4 shows the lightning discharge data of each simulation experiment scheme.

3.2. Lightning Simulation Experiment Based on Evolutionary Algorithm. Thunder is a discharge phenomenon in the atmosphere, mainly formed by cumulonimbus clouds. Cumulonimbus clouds will continue to move with changes in temperature and airflow. Friction generates electricity during movement, forming a charged cloud. The electric charge carried by different clouds is also different. Generally speaking, the negatively charged part of the lower thundercloud has a very large charge density, and the electric field strength reaches the critical value of air dissociation, which is the condition for linear lightning. The maximum field strength in a thunderstorm cloud is an important indicator parameter that characterizes the electrical activity of the thunderstorm cloud. Because the generation of lightning will neutralize the charge in the cloud and suppress the electric field strength in the cloud, the evolution of the maximum field strength in the thunderstorm cloud can reflect the lightning the suppression effect of the parameterized scheme on the electric field in the cloud. Table 5 shows the changes in the lightning electric field and the total number of flashes in the experiment.

3.3. Experimental Design of Active Protection against Lightning Discharge. In this experiment, based on the numerical simulation of lightning, a more active protection plan was designed, such as adding active lightning protection devices to related buildings and increasing lightning protection publicity. In the plan design, statistics are made on the losses and hazards caused by lightning in buildings, animals, livestock, and fires. This experiment will be carried out in a place where lightning activities are intensive, and the latest lightning protection devices will be used in this experiment, such as lightning rods, lightning belts and lightning nets, valve arresters, tubular arresters, and lightning protection wires. The experimental data are based on the historical data provided by the local meteorological bureau, combined with the numerical simulation method of this study, to explain the lightning protection principle.

Table 4: Comparison of discharge time data.

Discharge time (min)	Electrification plan			
	Option 1	Option 2	Option 3	Option 4
0	18.500	18.500	18.500	18.500
5	20.600	20.500	20.500	20.500
10	22.800	23.658	21.900	23.700
15	24.900	25.820	23.600	25.700
20	26.500	27.600	25.400	28.500
40	27.700	28.658	26.500	29.600

Table 5: Lightning electric field and changes in total number of flashes.

Time	Electric field strength (k·v/m)	Total number of flashes
10	0	0
15	0	0
20	16	0
25	45	3
30	78	5
35	92	6
40	89	4
45	84	5

4. Lightning Discharge Numerical Simulation and Active Protection Experiment Results Based on Quantum Heuristic Evolution Algorithm

4.1. Lightning Discharge Experiment Data Analysis. According to Table 4 and the voltage changes in the experiment, we have obtained the discharge experiment data and voltage change diagram during the discharge experiment, as shown in Figure 7.

Only one negative CG flash occurred in the above four schemes and the time was about 25 minutes, that is, the time when the sub-positive charge area appeared. This is because the charge structure of thunderstorm clouds generally presents a tricolor charge structure. Both the spatial distribution and the charge density are large, so the field strength of the primary negative charge area and the secondary positive charge area will be increased, and the negative pilot can be triggered and transmitted to the ground, both of which will produce negative CG flashes. The increase in the collision coefficient did not change the overall discharge frequency, nor did it change the polarity of the occurrence of CG lightning. However, there are some differences in the discharge time. The first discharge types are all cloud flashes, and the number of cloud flashes is much higher than that of ground flashes. With the increase in the collision coefficient, the discharge time at the later stage of the development of thunderstorm cloud is obviously advanced. The last cloud flash of Scheme 1 is 0.958 s earlier than the last cloud flash of Scheme 2, and the last three

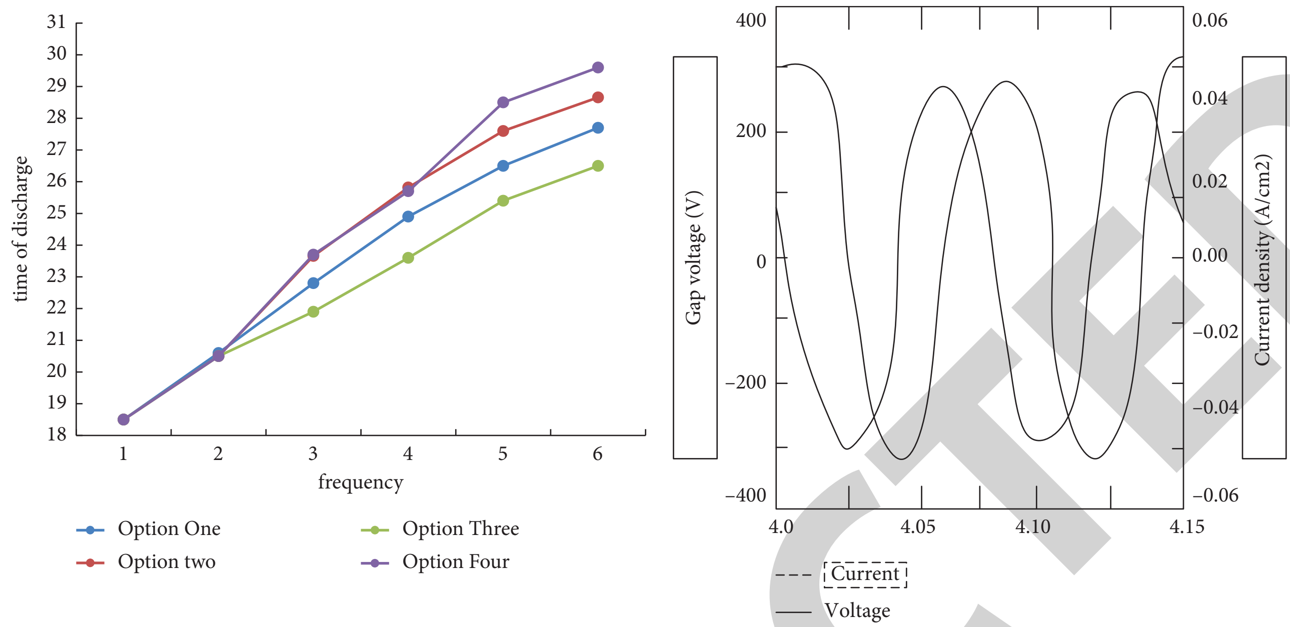

Figure 7: Data analysis of discharge experiment.

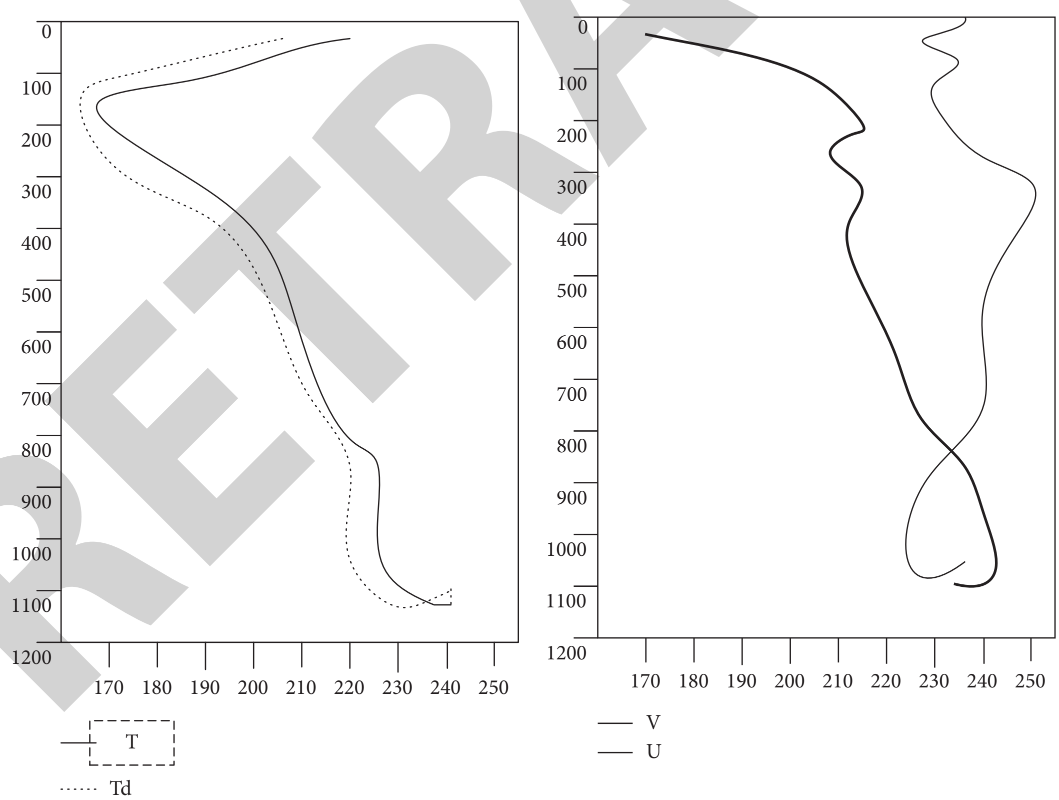

Figure 8: Initial temperature, dew point, and horizontal wind settings in the simulation.

lightning of Scheme 3 are all earlier than the previous scheme, and each discharge time is about 1.1 s earlier. Combining the comparison of the previous charge structure distribution map, it can be seen that the area with high discharge frequency corresponds to the area with higher charge structure density. That is to say, the stronger the charge structure, the more it can promote the discharge of lightning. After the discharge occurs, the charge density

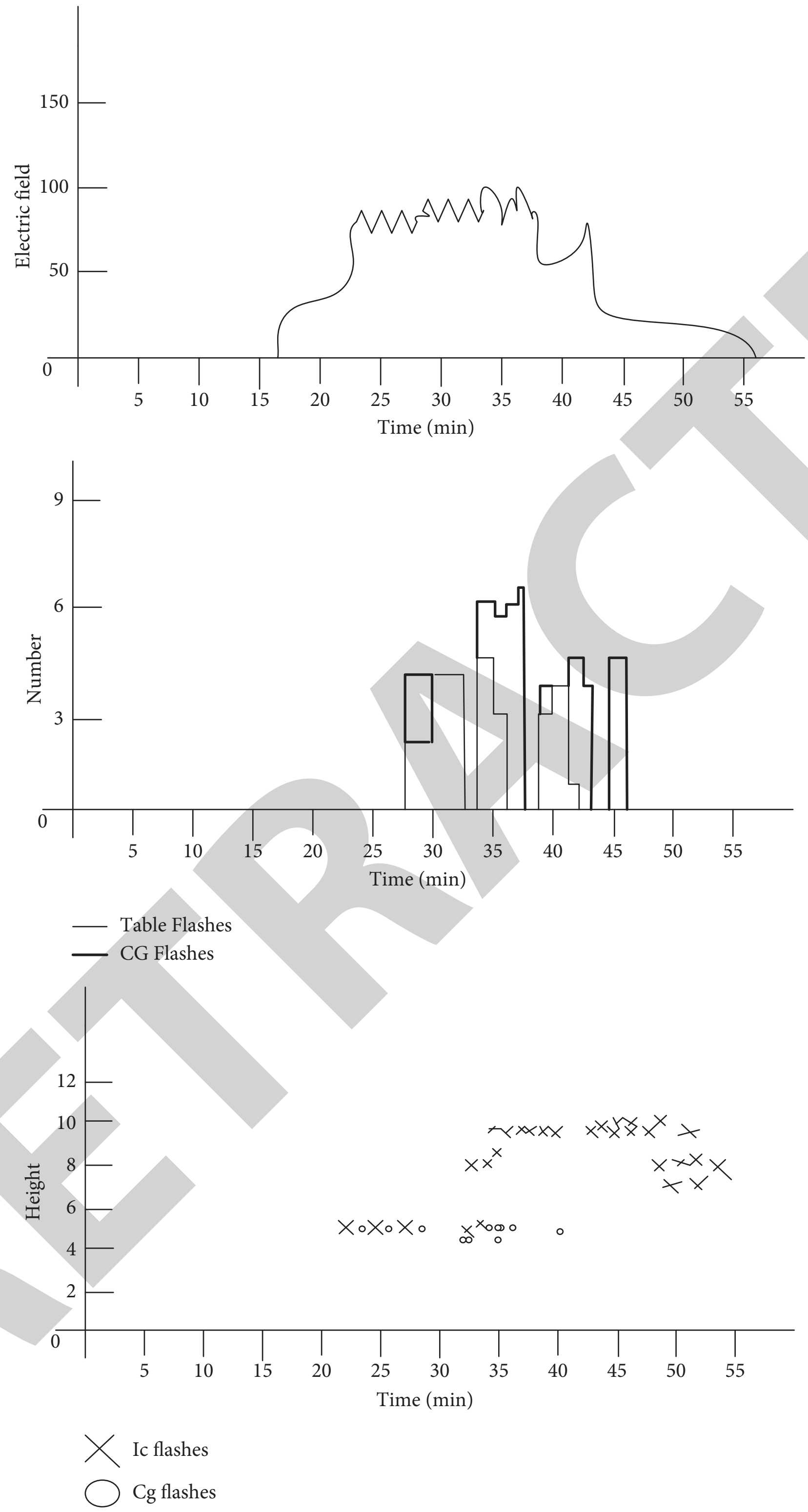

Figure 9: Evolution of some parameters during the simulation.

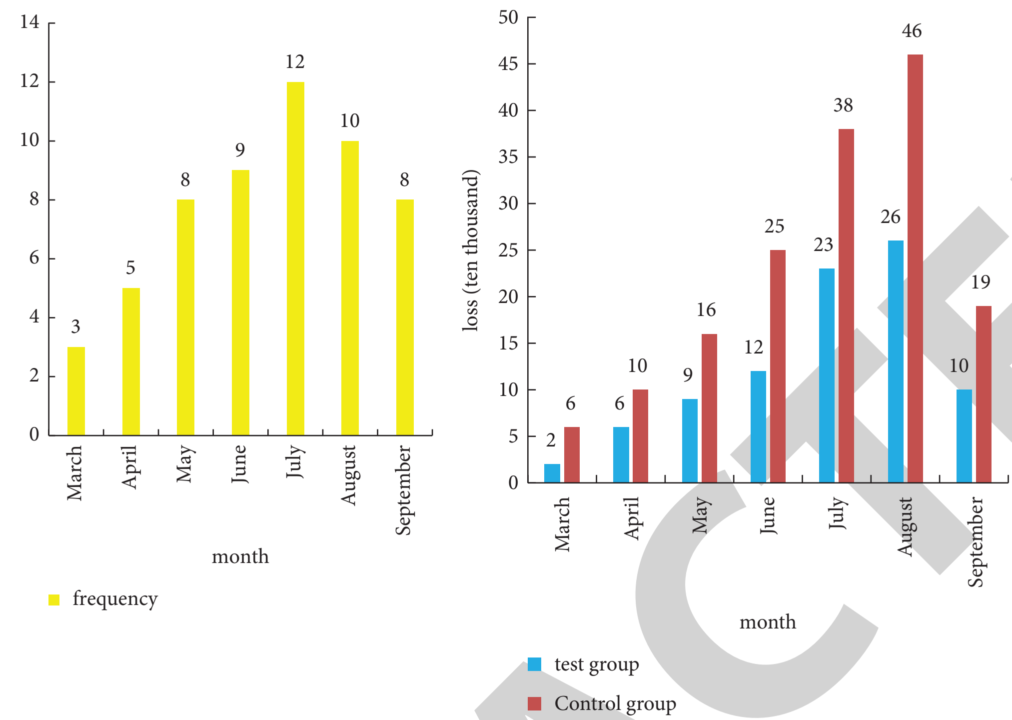

Figure 10: Effect of active protection.

decreases, thereby inhibiting the further increase in the charge intensity makes the development of the charge structure suppressed, and the thunderstorm cloud enters a period of dissipation. This shows that the protection of lightning should be based on prevention. Lightning is generated for a very short period of time, and it is difficult to protect after lightning.

4.2. Lightning Simulation Experiment Analysis Based on Evolutionary Algorithm. In this part of the experiment, the lightning numerical simulation experiment was carried out. In the experiment, the initial temperature and dew point of the experimental environment were set, as shown in Figure 8.

According to Figure 8, the setting of various environmental factors in the experimental environment is known, mainly simple design of initial temperature, dew point, and horizontal wind. After the environmental factors are determined, the appearance trajectory and radiation intensity of the simulated lightning can be determined according to various parameters of the environment. According to the design of these experiments, the data in Table 5 are obtained. From the data in Table 5, the changes in the lightning electric field and the total number of flashes in this experiment can be obtained, as shown in Figure 9.

It can be seen from Figure 9 that the electrification process of thunderclouds gradually increases from about 20 minutes. After 45 minutes, the thunderstorm entered the ablation phase, and the maximum electric field intensity began to gradually decrease. During the development process, its value shows the vibration process caused by lightning. Its value never exceeds 132 kV/m, indicating that the lightning parameterization scheme can better limit the maximum field strength in the cloud.

4.3. Analysis of Experimental Results of Active Protection against Lightning Discharge. In the experiment of this article, an active protection experiment was carried out on thunder and lightning, and a comparative experiment was carried out for the common lightning disasters in a certain place, and the number of lightning disasters that occurred before and after the experiment and the losses caused were statistically analyzed. The statistical results are shown in Figure 10.

From Figure 10, it can be concluded that summer is the season of frequent thunder and lightning weather, and the disaster losses caused by thunder and lightning are not few in this area every year. After the comparison of this experiment, the lightning discharge numerical simulation based on evolutionary algorithm, and the introduction of active protection, the lightning disaster loss in this area is more than 30% less than that of some areas without active protection. Therefore, taking some active lightning protection measures is an important measure to avoid lightning disasters.

5. Conclusions

Through the experimental analysis of this article, the following conclusions are drawn: using the quantum heuristic evolution algorithm to simulate lightning discharge, the results can be obtained quickly and it has a guiding role for experimental research and theoretical analysis. At the same time, man-made active protective measures can greatly reduce the losses caused by lightning disasters. In the experiments in this study, the numerical simulation of lightning discharge based on evolutionary algorithms and the results of active protection experiments show that active self-protection can recover more than 30% of the losses caused by lightning disasters.

Data Availability

The data of this study can be obtained through email to the authors.

Disclosure

A preprint has previously been published [30].

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this work.

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