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Abstract: Thunder is a discharge phenomenon that often occurs in nature. Due to its physical influences such as strong current, high temperature, strong shock waves, strong electromagnetic radiation, etc., it has a huge destructive effect instantly, which may bring serious threats to people's lives and property safety. This paper aims to study the lightning discharge numerical simulation and active protection based on the quantum heuristic evolutionary algorithm, and proposes 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. 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 caused by disasters.

Keywords: Evolutionary Algorithm, Numerical Simulation of Lightning Discharge, Active Lightning Protection, Quantum Algorithm

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. Especially 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. 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, in order 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, adopt Measures are necessary and reasonable. As a new intelligent optimization algorithm, 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 L proposed an effective co-evolutionary quantum algorithm (ECQA) for the traditional quantum evolutionary algorithm that is difficult to find the global optimal solution in the multi-modal optimization problem. The ECQA combines cooperative evolution and adaptive mutation strategies, which can independently complete the evolution process and effectively exchange evolution information [1]. In order to improve the performance of traditional quantum-inspired evolutionary algorithms, Ming S proposed a novel quantum-inspired co-evolutionary algorithm (NQCEA) in his research [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 G 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. In order 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 NV 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 Z researched and summarized the latest developments in lightning protection from the aspects of lightning positioning and observation, lightning physics, lightning electromagnetic transients, 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

(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].

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.

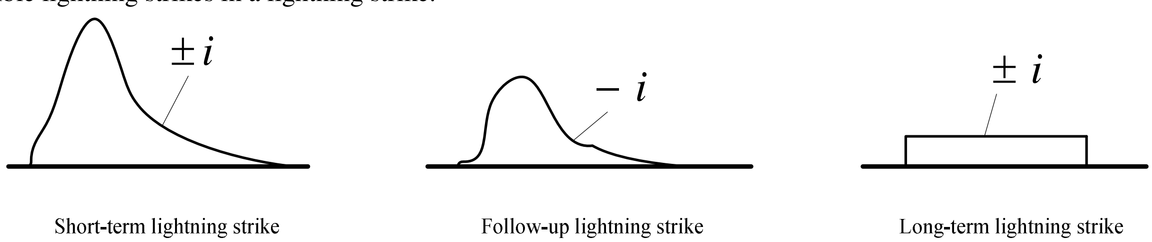


Figure 1 Three possible lightning strikes in a flash strike

(2) Description of lightning current

1) Waveform of lightning current

Figure 2 shows a schematic diagram of lightning waveforms.

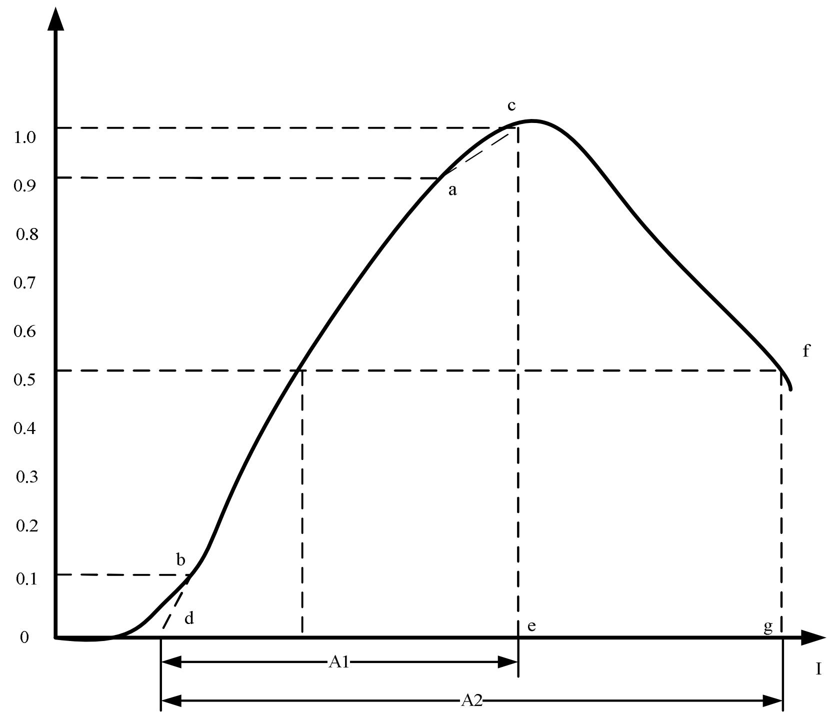


Figure 2 Lightning waveform

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, draw three vertical lines perpendicular to the current on the vertical axis. The first two vertical lines intersect the head of the wavy curve. Use a and b to connect the line created between a and b. The straight line 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 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 430kA, 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 200kA. 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.

Table 1 The 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 The 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

(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.

$$R = \int_0^t i^2 M dt \quad (1)$$

Where R represents heat, i represent 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.

$$\Delta t = \frac{R}{mc} \quad (2)$$

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, chemical liquid pipelines, etc. 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 exceeds 4mm, it can be directly resistant to lightning strikes and can be directly used to receive lightning.

(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 [12]. 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 electrodynamics effects of direct thunder on people and buildings. The other is the secondary effect of lightning, that is, electrostatic induction and electromagnetic induction caused by lightning current [13-14]. Figure 3 is a schematic diagram of part of the damage caused by lightning.

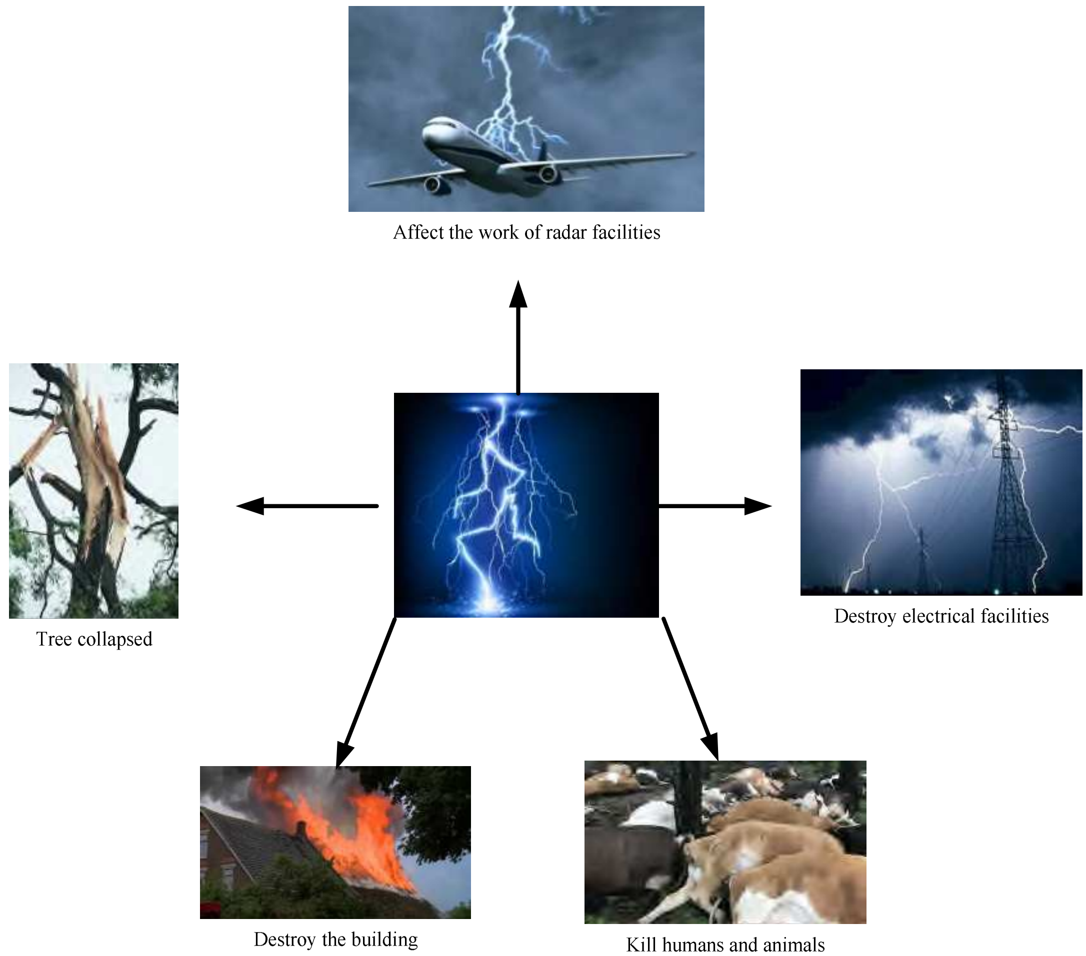


Figure 3 Harm from lightning

(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 [15]. 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). [16]. Nowadays, the importance, urgency and complexity of lightning protection work have greatly increased. Therefore, in order 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 [17-18]. Figure 4 is a diagram of the lightning protection system.

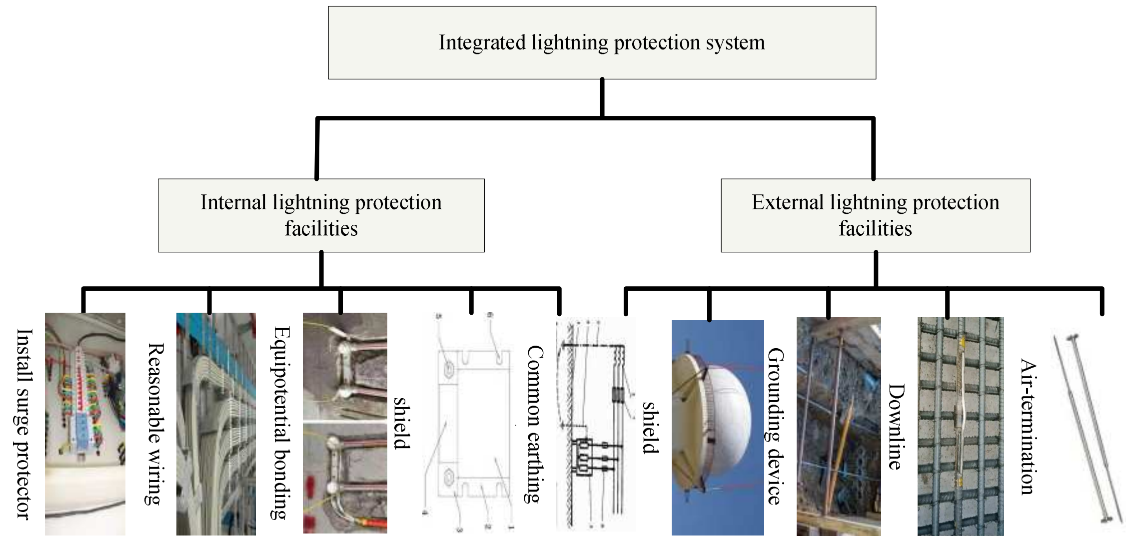


Figure 4 comprehensive lightning protection system diagrams

2.2 Quantum Heuristic Evolutionary Algorithm

Evolutionary algorithm is a self-organization and adaptive artificial intelligence technology, which solves problems by simulating the evolutionary process and mechanism of biology [19]. According to Darwin's theory of natural elimination and Mendel's genetic variation, biological evolution is achieved through replication, mutation, competition and selection [20]. The original reason that individuals can evolve is to use selection operations. In order 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 [21-22]. 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. Genetic algorithm is the most commonly used algorithm in evolutionary algorithms. Figure 5 is a schematic diagram of the genetic algorithm operation process.

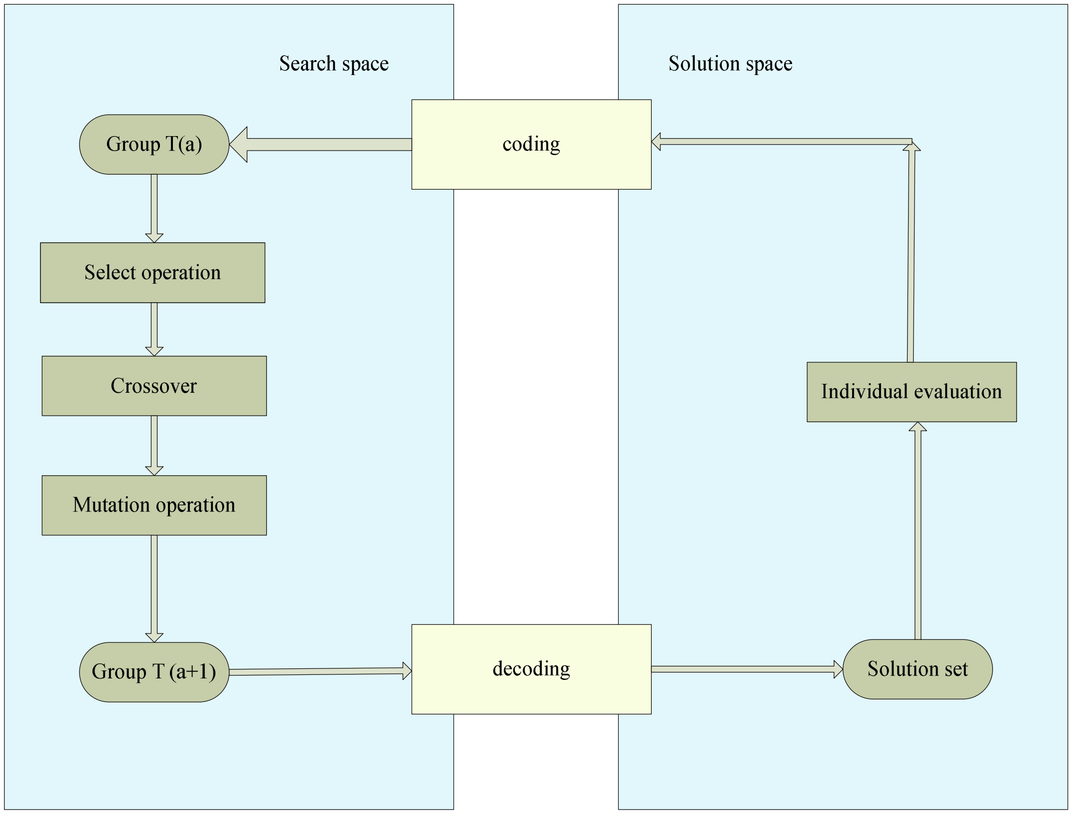


Figure 5 Schematic diagram of the operation process of genetic algorithm

(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: $\begin{bmatrix} \partial \\ \delta \end{bmatrix}$. 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.

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

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

(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 [23]. 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 parents [24]. 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 [25].

(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.

1) Quantum NOT gate N

The quantum NOT gate is a one-bit gate, and its update operation is:

$$\begin{bmatrix} \partial_i^{'} \\ \delta_i^{'} \end{bmatrix} = N * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix} = \begin{bmatrix} \delta_i \\ \partial_i \end{bmatrix} \quad (4)$$

Among them, $(\partial_i, \delta_i)^t, (\partial_i^{'}, \delta_i^{'})^t$ 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.

$$\begin{bmatrix} \partial_i^{'} \\ \delta_i^{'} \end{bmatrix} = X * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} * \begin{bmatrix} \partial_i \\ \delta_i \end{bmatrix} \quad (5)$$

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

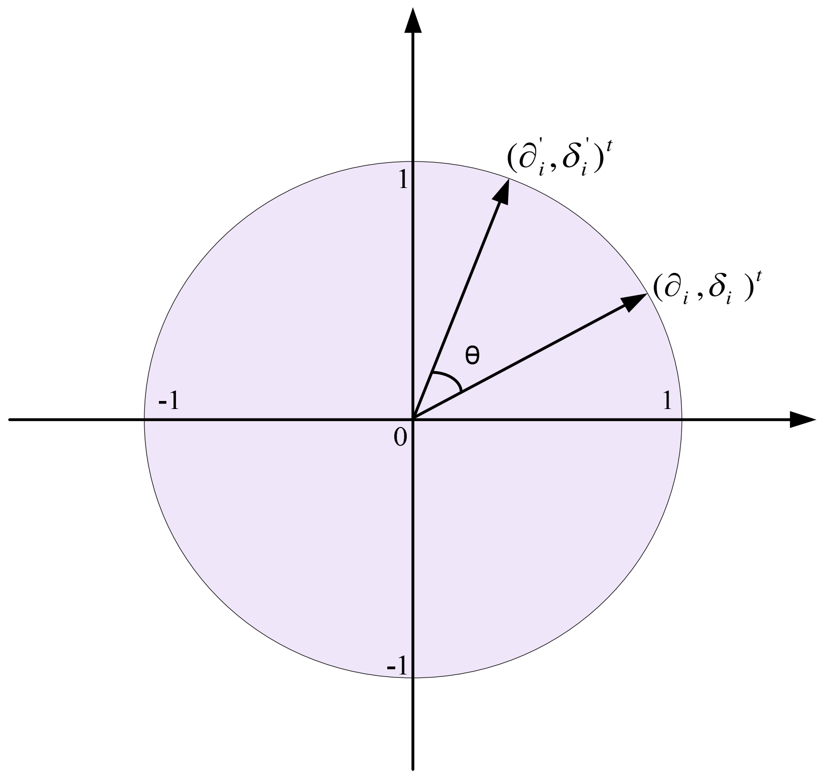


Figure 6 schematic diagrams of the polar coordinates of the quantum rotating gate

Among them, $(\partial_i, \delta_i)^t$ represents the state of i-the qubit before rotation, and $(\partial_i^{'}, \delta_i^{'})^t$ represents the state of i-the 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:

$$(\partial_i^{'}, \delta_i^{'})^t = L(\partial_i, \delta_i, \theta) \quad (6)$$

$$(\partial_i^{''}, \delta_i^{''})^t = X(\theta)(\partial_i, \delta_i)^t \quad (7)$$

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<ε<1, if $\left|\partial_i^{''}\right|^2 \le \varepsilon$ or $\left|\delta_i^{''}\right|^2 \ge 1-\varepsilon$, then:

$$(\partial_i^{'}, \delta_i^{'})^t = \left(\sqrt{\varepsilon}, \sqrt{1-\varepsilon}\right)^t \quad (8)$$

If $\left|\partial_i^{''}\right|^2 \ge 1-\varepsilon$ or $\left|\delta_i^{''}\right|^2 \le \varepsilon$, then:

$$\left(\partial_i^{'}, \delta_i^{'}\right)^t = \left(\sqrt{1-\varepsilon}, \sqrt{\varepsilon}\right)^t \quad (9)$$

In other cases:

$$\left(\partial_i^{'}, \delta_i^{'}\right)^t = \left(\partial_i^{''}, \delta_i^{''}\right)^t \quad (10)$$

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

$$\begin{bmatrix} \partial_1^{'} \\ \delta_1^{'} \\ \partial_2^{'} \\ \delta_2^{'} \end{bmatrix} = M * \begin{bmatrix} \partial_1 \\ \delta_1 \\ \partial_2 \\ \delta_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \partial_1 \\ \delta_1 \\ \partial_2 \\ \delta_2 \end{bmatrix} = \begin{bmatrix} \partial_1 \\ \delta_1 \\ \partial_2 \\ \delta_2 \end{bmatrix} \quad (11)$$

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.

(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 Prob(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 m-the 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:

$$\Pr ob(M_m^n) = \prod_{i=1}^{y} P_i \quad (12)$$

In,

$$P_i = \begin{cases} |\partial_i|^2, b_i^n = 0 \\ |\delta_i|^2, b_i^n = 1 \end{cases} \quad (13)$$

$$\Pr ob(M(n)) = \frac{1}{x} \sum_{m=1}^{x} \Pr ob(M_m^n) \quad (14)$$

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 [26-27].

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 $M(n)=(M_1^n,M_2^n,...M_m^n,...M_x^n)$, the m-the binary chromosome is $M_m^n=(b_1^n b_2^n..b_i^n..b_{y-1}^n b_y^n)$, which defines it:

$$C_b\left(M_m^n\right)=\frac{1}{y}\sum_{i=1}^{y}\left|1-2\left|\partial_i\right|^2\right| \qquad (15)$$

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. According to, define the average convergence of the quantum population:

$$C_{av}(M(n))=\frac{1}{x}\sum_{m=1}^{x}C_b\left(M_m^n\right) \qquad (16)$$

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:

$$C_{av}(M(n))>\gamma \qquad (17)$$

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:

$$C_{\max}(M(n))>\gamma \qquad (18)$$

If the quantum update uses an L gate instead of a quantum revolving gate, formulas 17 and 18 should be revised as follows:

$$C_{av}(M(n))>(1-2a)\gamma \qquad (19)$$

$$C_{\max}(M(n))>(1-2a)\gamma \qquad (20)$$

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 [28]. The upper part of the cumulonimbus cloud is generally high, up to 20km, 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. 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 [29]. 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 lightning’s occur during the detection of an air probe, the potential of a specific lightning cannot be obtained. Circumstances, so it is still very difficult to detect thunderstorm clouds using existing observation techniques. Therefore, it is very necessary to use numerical simulation to study the electrification and discharge process in thunderstorm clouds.

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 mechanism in thunderstorm clouds is the main reason that causes the particles of water in the cloud to carry different positive and negative charges to form different charge structures. Many scholars have proposed and developed various research methods to explain the distribution characteristics of the charge structure of the dipole, triple, and multiple of the thunderstorm cloud, as well as the charge of the charged particles of the cloud charge mechanism. For electricity and polarity issues, the main mechanical devices are divided into thermoelectric charging, induction charging, non-inductive charging, particle diffusion, secondary ice crystal charging, etc. Most numerical simulation studies have shown that the charge of thunderclouds mainly comes from induced and non-inductive charging. Among them, the non-inductive charging mechanism is very sensitive to the ice phase process, especially the second characteristic mode involving the spatial distribution and scale of non-inductively 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 grauil 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:

$$\left(\frac{\alpha D_{eg}}{\alpha t}\right)_d = \left(\pi^3/8\right)\left(\frac{6W_g}{\chi(4.5)}\right)E_{gc}E_rQ_{0g}Q_cT_c^2 \left[\pi\chi(3.5)\beta*\cos\theta\cos E_2T_g^2-\chi(1.5)D_{eg}/(3Q_g)\right] \tag{21}$$

Inductive electrification is under the action of a certain thunderstorm environment electric field, 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:□□

$$\left(\frac{\alpha Q_{eg}}{\alpha t}\right)_d = \left(\pi^3/8\right)\left(\frac{6W_g}{\chi(4.5)}\right)E_{gc}E_r N_{0g} N_c T_c^2 \left[\pi\chi(3.5)\beta*\cos\theta\cos E_2 T_g^2 - \chi(1.5)Q_{eg}/(3N_g)\right] \quad (22)$$

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) 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. And the conversion scheme is the basic requirement of the numerical simulation study of thunderstorm cloud-electricity process.

3) Initial mode setting

The starting calculation formula of the mode, the initial values of the parameters are:

$$\begin{aligned} \partial &= \partial_0(z) \\ \alpha &= \alpha_0(z) \\ \beta &= \beta_0(z) + \Delta\beta \\ \delta &= \delta_0(z) + \Delta\delta \\ W &= W_{v0}(z) + \Delta W_{v0} \end{aligned} \quad (23)$$

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, or 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:

$$\beta = \beta_0 + \Delta\beta * \cos^2\left(\frac{\pi}{2}\varepsilon\right) \quad (24)$$

$$W_v = W_{v0} + (W_{vn} - W_v)\cos^2\left(\frac{\pi}{2}\varepsilon\right) \qquad (25)$$

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.

Table 4 Comparison of discharge time data

Discharge time	Electrification plan			
	Option One	Option two	Option Three	Option Four
	18.500	18.500	18.500	18.500
	20.600	20.500	20.500	20.500
	22.800	23.658	21.900	23.700
	24.900	25.820	23.600	25.700
	26.500	27.600	25.400	28.500
	27.700	28.658	26.500	29.600

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. And 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.

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

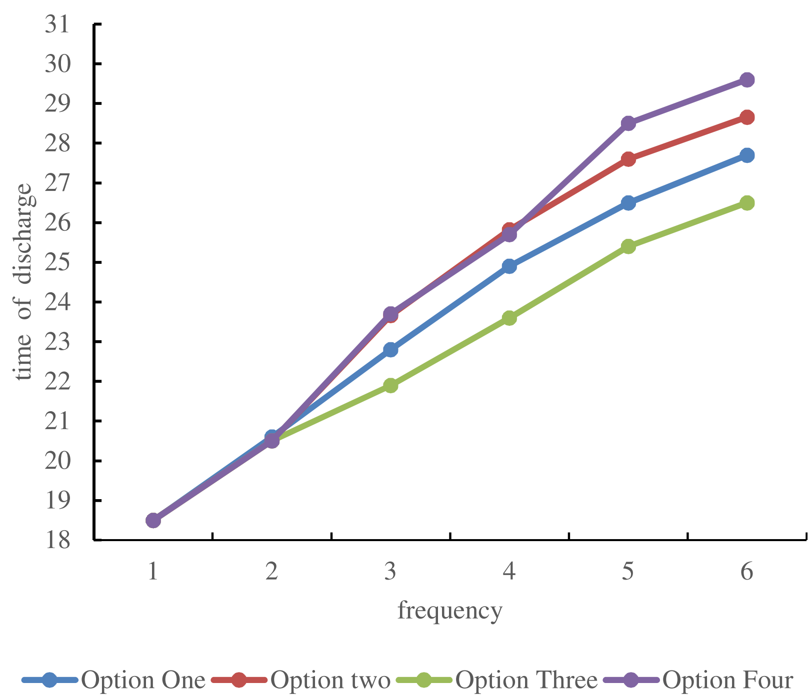
3.3 Experimental Design of Active Protection Against Lightning Discharge

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, lightning protection wires, etc.

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:



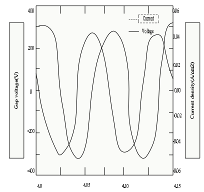


Figure 7 Data analysis of discharge experiment

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 of 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 0.958s earlier than the last cloud flash of Scheme 2, and the last three lightning of Scheme 3 are all earlier than the previous scheme, and each discharge time is about 1.1s 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 decreases, thereby inhibiting the further increase of the charge intensity makes the development of the charge structure suppressed, and the thunderstorm cloud enters a period of dissipation.□□

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:

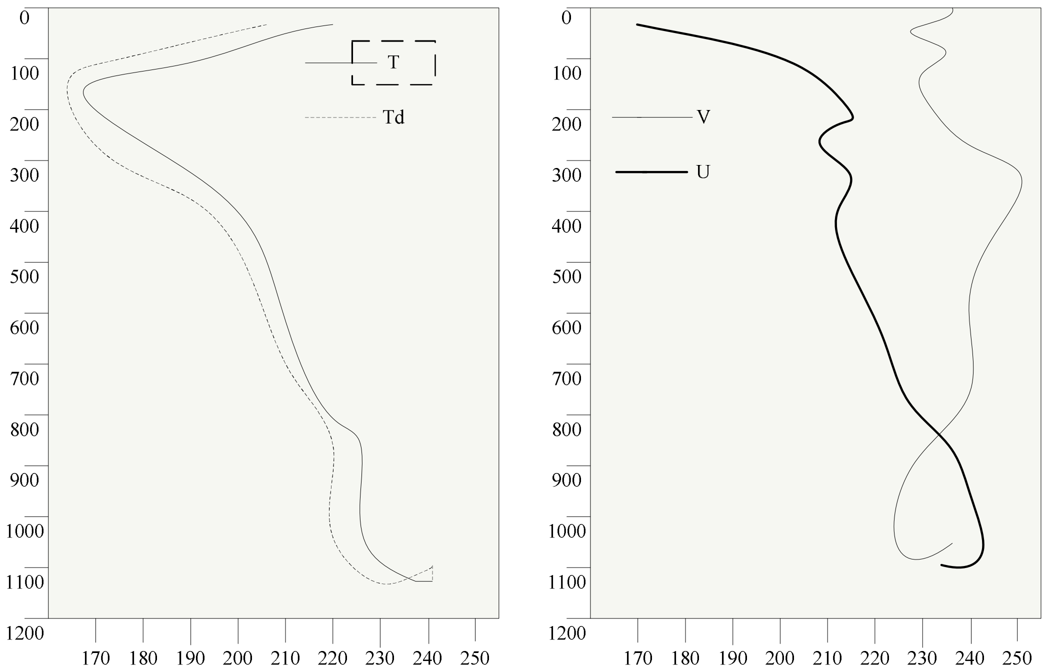


Figure 8 The initial temperature, dew point and horizontal wind settings in the simulation

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. 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:

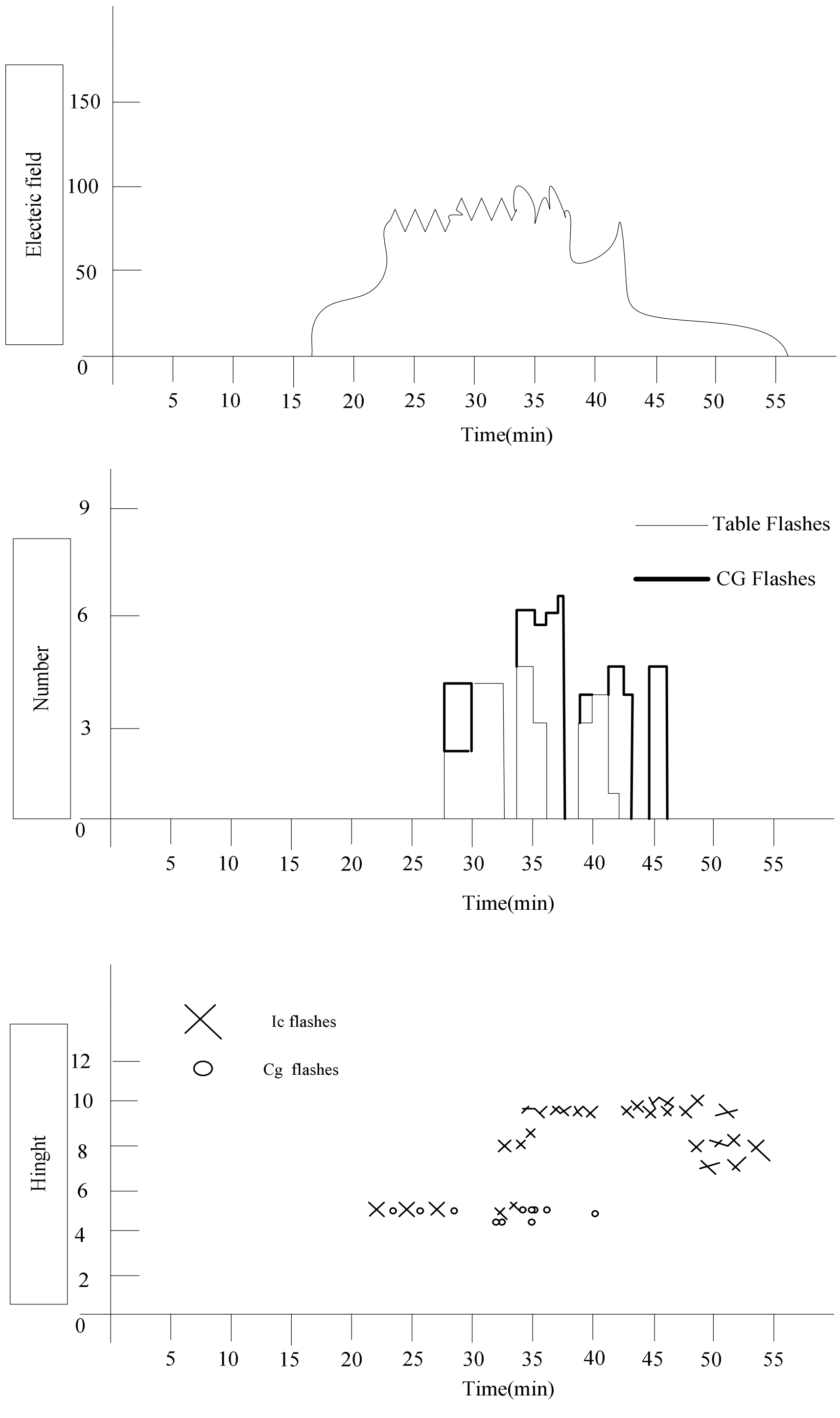


Figure 9 The evolution of some parameters during the simulation

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. And its value never exceeds 132kV/m, indicating that the lightning parameterization scheme can better limit the maximum field strength in the cloud.

4.3 Analysis of Experimental Results 0f 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 occurred before and after the experiment and the losses caused were statistically analyzed. The statistical results are shown in Figure 10:

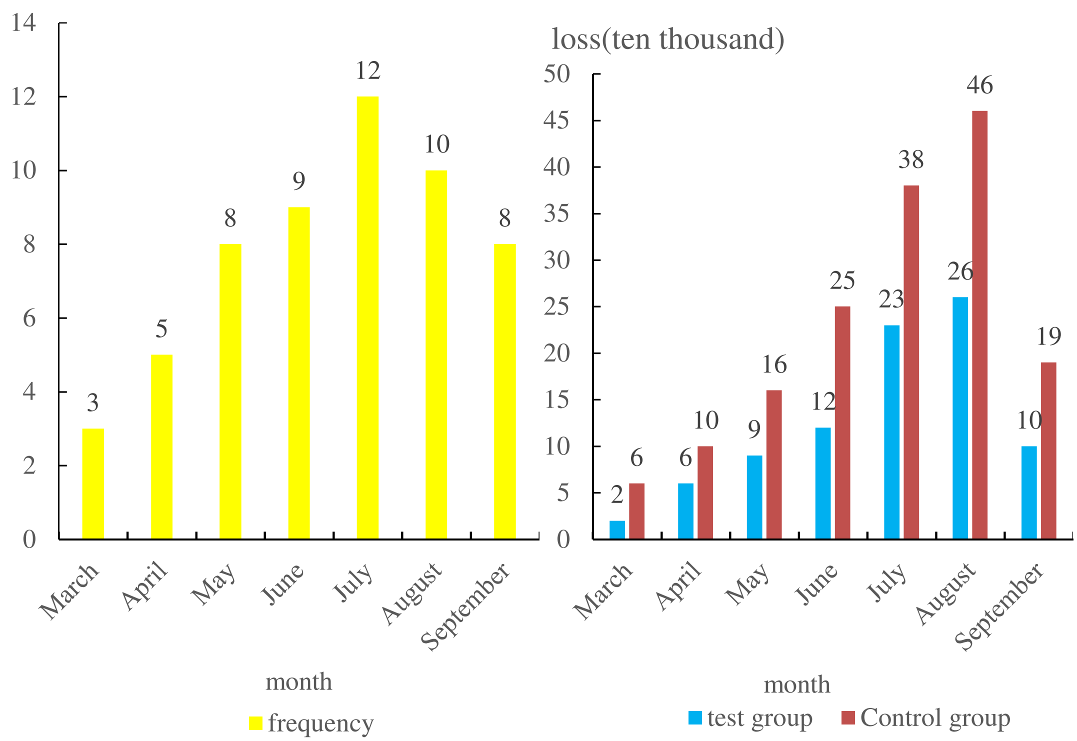


Figure 10 The effect of active protection

From Figure 10, it can be concluded that the 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: By using 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 paper, 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.

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