Computer Life (CPL) ISSN: 1819-4818
DELIVERING QUALITY SCIENCE TO THE WORLD

Energy Control Strategy of Multi-Microgrid Based on CA and Ant Colony Optimization under Island Mode

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Abstract: Research on energy control aspect of multi-microgrid is still a bottleneck at present, based on this, the energy control of multi-microgrid under island mode is studied in this paper, and the control model of multi-microgrid is built based on cellular automata and ant colony optimization where the cellular automata can realize the energy change monitoring within the micro-grid under island mode, the ant colony optimization is used to calculate the feasible solution of the energy control, on this basis, the energy control strategy of multi-microgrid based on CA and ant colony Optimization is proposed.
Keywords: multi-microgrid, cellular automata, ant colony optimization, island mode, energy control.

1. NTRODUCTION

In recent years, the development and utilization of renewable energy has been highly valued by the international community for influence of energy crisis, environmental pollution and climate change, vigorously developing renewable energy has become important content that various countries in the world adjust energy strategy and change power development mode [1-2].

At present, the research work of micro-grid is only in the initial stage in China compared to the United States, Japan and other developed countries. With the increasing size of China's power system, the national power system faces more and more high security and reliability pressure, the development of micro-grid is an effective measure to ease the current power supply pressure.

A distributed voltage control algorithm of low voltage micro-grid is proposed in reference [3], the active power of distributed power is used to carry out voltage control to achieve voltage regulation and improve the power supply ability, but only the control algorithm of voltage is proposed, there is no specific coordination control strategy to describe. Reference [4] aims at equal control mode of micro-grid which does not rely on communication, analyzes voltage/reactive droop characteristics multi micro-sources in parallel based on the droop control strategy, puts forward a kind of droop control strategy on the basis of composite virtual impedance and adaptive droop coefficient, but the reference only is aimed at voltage control and reactive distribution, there are no corresponding coping strategies when multi-microgrid fails. Reference [5] proposes the reactive voltage control strategy of microgrid based on MAS in under island mode, and the control method that combines distributed energy release, switched capacitor and switched load is used to solve the control problem of micro-grid voltage under island mode but reference based on the control strategy of multi-agent system, the fault processing method is single and cannot deal with the complicated fault problem of micro-grid. The operation control and energy management technology of micro-grid formed by the multi-voltage source are studied in the reference [6], including the energy converter mode suitable for the various operating modes of micro-grid and adaptive improved droop control, the control strategy of micro-source that can be dispatched based on hybrid stored energy, but the reference does not specifically propose dispatched control strategy of micro-source and the solution to the fault.

Cellular Automata (CA) model is used to study traffic, pattern optimization of rural land, finance and industrial production at this stage, the application of power system is still in the initial stage, the application in micro-grid is less, the cellular automata will have some advantages when applying in micro-grid due to its own flexibility. A distributed coordination control strategy of micro-grid based on MAS and CA is proposed under the island mode in reference [7], a two-layer architecture model based on MAS and cellular automata is built and it is used to establish "top-down" distributed coordination control model of multi- microgrid, adjust active and reactive power condition of the micro-source and bus voltage and frequency of system, but the functions of reference MAS and cell automata overlap, the control strategy is relatively simple, and range which can cope with the fault problem is narrow.

Literature [10] take minimum investment and operation cost of user side and network loss cost as the optimization goal, different weight coefficient is set up combined with the importance of costs, and the multi-objective optimization model was established, ant colony optimization is used to calculate, strong solving ability of ant colony optimization is shown, and have validity and application value of the simulated evolution optimization.

Based on some research on energy control micro-grid, this paper draws lessons from the B/S architecture of the web browser (browser/server mode), simplifies the calculation, maintenance and use of multi-microgrid nodes, the complex issues are handled by the center CA. Under the island mode of micro-grid, the CA is used to monitor the running status of each node of the micro-grid, and the center CA collects the fault problem uniformly, then the ant colony optimization is used to calculate feasible solution. On this basis, the energy control strategy of multi-microgrid is proposed.

2. NETWORK STRUCTURE AND ENERGY CONTROL OF MULTI-MICROGRID SYSTEM

2.1 Network structure of multi-microgrid system

According to DG, the location that loads access micro-grid and the number of PCC, micro-grid can be divided into three types: they are single DG, single load, single PCC micro-grid; multi-DG, single load, single PCC micro-grid; multi-DG, multi-load, multi-PCC micro-grid, respectively. The multi-microgrid system is composed of three sub-microgrid that can run island in this paper. When the switch 1 is disconnected, A, B, C three sub-microgrid enter into isolated network mode. This multi-microgrid includes wind-mill generator, photovoltaic generator, micro-gas turbines, capacitor, load, transformer, inverters, circuit breakers, bus bar, power connection cables and other units. The system structure is shown in the Fig. 1

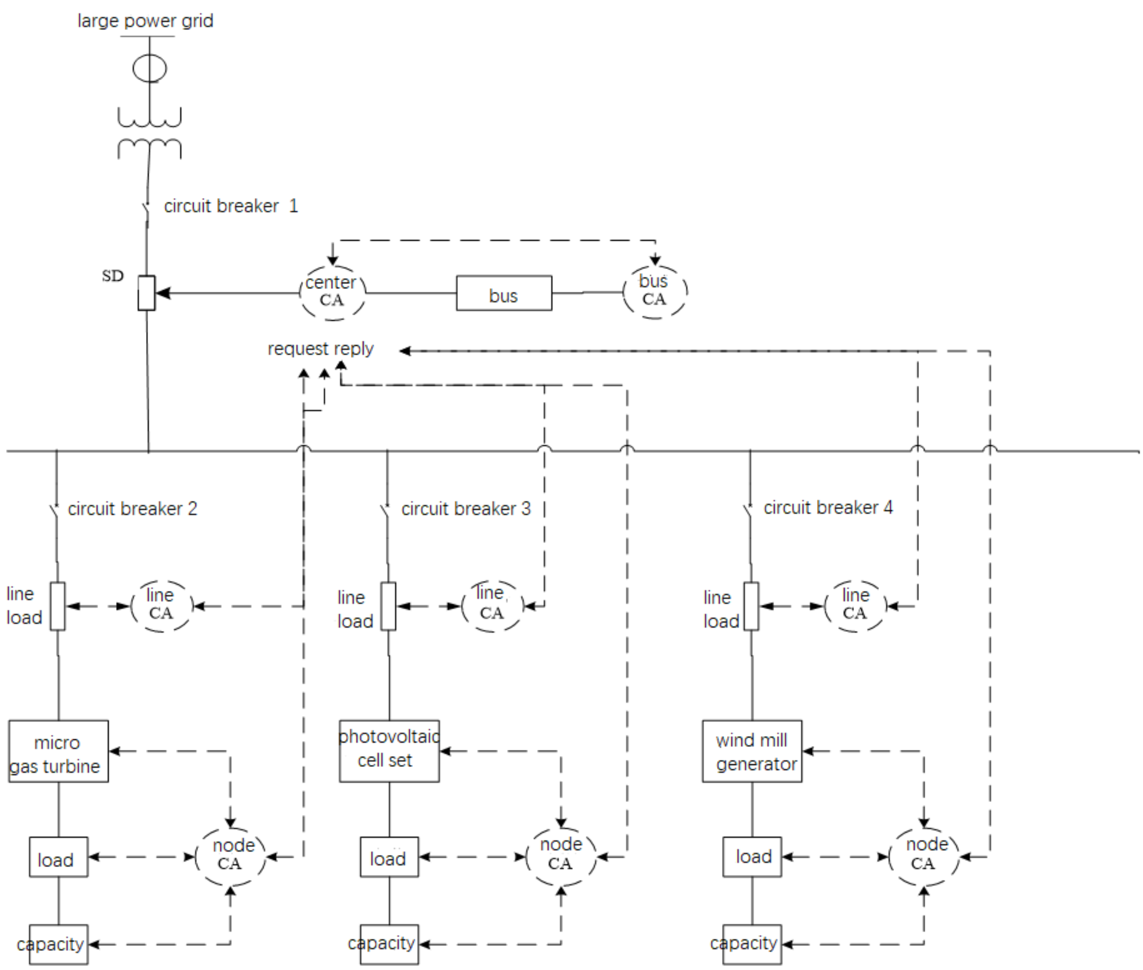

Fig. 1 system structure of multi-microgrid

2.2 Energy characteristics of island operation of micro-grid

When the island is running, due to the lack of voltage and frequency support of external large grid, frequency control of micro-grid has a certain challenge. At this point, the load of micro-grid are all supplied by the distributed Generation (DG for short), which requires the micro-grid itself to maintain its supply and demand balance of internal power, also ensure that the voltage and frequency is relatively stable, but the adjustment capacity of micro-grid itself does not necessarily meet the load requirements. If the load fluctuates greatly, then it is difficult for the micro-grid to realize regulation of voltage, and even the collapse of voltage occurs. If the adjustment capacity of micro-grid can meet the requirement of load change, load changes, especially reactive loads can also cause large fluctuations in voltage. Therefore, under the island operation mode, it is necessary to comprehensively consider the load change and the adjustment capacity of micro-grid itself. When a sub-microgrid of micro-grid is in the island mode, it is difficult for itself to realize power balance between supply and demand, whether there is interaction among sub-microgrids or not, how to maintain the bus voltage and stability of output frequency is very necessary to study at present. This paper puts forward control strategy of multi-microgrid based on CA and ant colony optimization to solve this problem, the CA trace and detect running status of all nodes of sub-microgrid, and communication between nodes CA and center CA, ant colony optimization is used to calculate the optimized feasible solution.

2.3 Mathematical model of micro-grid operation

For any one sub multi-microgrid, the reactive power balance equation of each node in the sub-microgrid is [8]:

$$Q_{\mathrm{i}} = \sum_{j} B_{ij} U_j (U_j - U_i) + F_i \tag{1}$$

Bij is the mutual admittance between nodes i and j; Ui and Uj are the voltages between i and j, respectively; Fi is the reactive power flow of injected node i of adjacent micro-grid in the formula. In this paper, influences among multi micro-grid are not considered, here Fi = 0.

The vector form is used to show interest of all the load and generator vectors in the area, and obtain:

$$Q = \begin{bmatrix} Q_L \\ Q_G \end{bmatrix} \tag{2}$$

And

$$U = \begin{bmatrix} U_L \\ U_G \end{bmatrix} \tag{3}$$

$$F = \begin{bmatrix} F_L \\ F_G \end{bmatrix} \tag{4}$$

Equation (1) can be written as:

$$\dot{Q} = D\dot{U} + \dot{F} \tag{5}$$

Among them

$$D = \begin{bmatrix} D_{LL} & D_{LG} \\ D_{GL} & D_{GG} \end{bmatrix} \tag{6}$$

In formula (5), D is the sensitivity matrix, namely, and related parts of voltage and reactive power in the power flow equations of Jacobian matrix, where DGG is mutual admittance among the micro power source feeders; DGL and DLG are mutual admittances between micro power source feeders and the load feeders; the DLL is the mutual admittance among the load feeders. Thus, the linearized system model can be expressed by the following sensitivity equation (assume F = 0) [8]:

$$\begin{bmatrix} \Delta Q_L \\ \Delta Q_G \end{bmatrix} = \begin{bmatrix} D_{LL} & D_{LG} \\ D_{GL} & D_{GG} \end{bmatrix} \begin{bmatrix} \Delta U_L \\ \Delta U_G \end{bmatrix} \tag{7}$$

In the formula (6): ΔUL is the change value of load voltage; ΔUG is the voltage change value of micro power source; ΔQL is the reactive power change value of load; ΔQG is the reactive power change value of micro power source.

If $C_U = -D_{LL}^{-1} D_{LG}, C_Q = -D_{LL}^{-1}$, then formula (6) is

$$\Delta U_L = C_U \Delta U_G - C_Q \Delta Q_L \tag{8}$$

In the formula: $C_U \Delta U_G$ does not affect the load node voltage; $C_Q \Delta Q_L$ is change value of load node voltage caused by reactive power disturbance. At this time, it is also the expression that load agent calculate the voltage deviation.

When micro-grid independently runs, the DG unit accesses the grid through the inverter, and supply power for the load. Output active power OF DG unit and reactive power P, Q are, respectively:

$$\begin{cases} \mathrm{P_i} = \dfrac{1}{|Z_i|}\left[\left(U_0 U_i \cos\delta_i - U_0^2\right)\cos\theta_i + U_0 U_i \sin\delta_i \sin\theta_i\right] \\ \mathrm{Q_i} = \dfrac{1}{|Z_i|}\left[\left(U_0 U_i \cos\delta_i - U_0^2\right)\sin\theta_i - U_0 U_i \sin\delta_i \cos\theta_i\right] \end{cases} \tag{9}$$

In the formula, U_0 U_i are the output voltage amplitude of bus voltage amplitude and DG_i unit, respectively, Z_i is the amplitude sum of output impedance and the line impedance of DG_i unit, θ_i is the impedance angle of the sum of the unit output impedance and line impedance, and δ_i is phase angle of the output voltage of DG_i unit. Because the low-voltage micro-grid line resistance is much greater than the reactance, when the line is longer, take $sin\theta_i \approx 1$, $\cos\theta_i \approx 0$, and in practice the output voltage phase angle of DG_i unit near to 0, so, formula (9) can be written as:

$$\left\{ \begin{array}{c} P_i \approx \frac{U_0}{|Z_i|}(U_i - U_0) \\ Q_i \approx \frac{U_i U_0}{|Z_i|}\delta_i \end{array} \right\} \tag{10}$$

3. STRUCTURAL DESIGN OF MICRO-GRID ENERGY CONTROL SYSTEM BASED ON CA AND ANT COLONY OPTIMIZATION

3.1 Description and construction of CA

Cellular automaton is a model with complex phenomenon that simulates spatial and temporal discretization through simple local operations. Cell are distributed in anywhere of regular grid in a certain discrete state, and they are updated with the same rules, which form a dynamic system by simple interaction. Cellular automata include cell, state, cell space, neighbor and conversion rules, the model as shown in Fig. 2 [9].

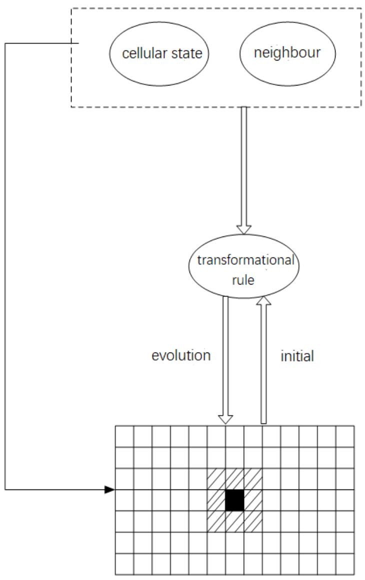

Fig. 2 cellular automata model

The cell is the basic element of CA. Under normal conditions, the cell stores state set in the 0, 1 two kinds of state, and the cellular space is the collection of the spatial grid of the cell. The neighbors in the CA act on the current cellular state, so that the state is transformed to direct adjacent cellular range. There are Moore type, von Neumann type, and extended Moore type in two-dimensional CA neighbors. In this paper, the Moore type is used in cellular automata model, its definition is:

$$N_{Moore} = v_i = (v_{ix}, v_{iy}), i = 1,2,3,......,8; \tag{11}$$

In the formula, |vix-v0x|≦1, |viy-v0y|≦1, (vix,viy) Z2, vi are cellular neighbors; (v0x, v0y) is the coordination of the center cell; (vix, viy) is the coordination of neighbor cell; Z2 represents the two-dimensional cellular space.

The evolution rule of CA is that cell determines function of next state based on its current state and the state of its neighbors. This function considers all the states of this cell and the transformation rule of these states, and builds a simple, discrete local transformation model. The cellular automata model can be defined as follows:

$$C_{t=1}^{i} = f(C_t^i, C_i^N); \tag{12}$$

In the formula: f-CA evolution rule; t-time; Cit- i cell state in t time; state combination of CNi-cell neighbor; Cit + i cell state in 1-t + 1 time.

This paper mainly uses four kinds of CA: power grid CA, center CA, line CA and node CA. The power grid CA is located on the connection line between the multi-microgrid and the large power grid-tied; this interface can be used to switch the grid-tied state of micro-grid and large power grid and micro-grid island running state, at the same time we can monitor the state that large power grid on the power supply state of multi-microgrid when multi-microgrid in the grid-tied state.

The main function of the center CA is to monitor and manage grid CA, the running state of line CA and the node CA, when any one CA sends an alarm signal to the center CA, the center CA will start a fault solution, collect node information of multi-microgrid, carry out algorithm operation, solve the failure problem, and play the control and management role for entire multi-micro network.

The main function of the line CA is to monitor the transmission status of each subnet, send the line fault to the center CA, and receive the control command returned by the center CA.

The main function of the node CA is to monitor the working state of the micro-source, load and capacitor in the node, and send the node fault to the center CA. When fault alarm happens in the node, it also needs to send the node information to the center CA, and receive operation information returned by the center CA, reset node status.

3.2 Introduction to ant colony optimization

Ant colony optimization is a heuristic algorithm, which has a strong ability to solve, in recent years, it has applied in many aspects. Specific steps of ant colony optimization are as follows:

1 initialize the pheromone concentration $\tau(0) = c$ (c is a constant).

2 Each ant randomly chooses a point as its initial point, at the same time, it selects the next point to arrive according to a random scale rule. The random scale rule is as follows: [11].

$$\mathrm{P}_{ij}^{k}(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha} \times [\eta_{ij}(t)]^{\beta}}{\sum\limits_{k \in allowed_k} [\tau_{ik}(t)]^{\alpha} \times [\eta_{ik}(t)]^{\beta}} & if \quad j \in allowed_k \\ 0 & others \end{cases} \tag{13}$$

In the formula, i j are starting points and the end points, respectively, d_{ij} is the distance between i and j, allowed_k is the set of points that have not been accessed, α and β are two constants.

3 set the number of circulation, i.e.

4 set the number of ants.

5 When the ant starts from one point to another, the pheromone on its path is updated.

6 The above steps are executed to know that each ant has found a feasible path containing all nodes as the current feasible solution.

7 Find the shortest path in all feasible solutions, which is the optimal path in this iteration.

8 Repeat steps 2-7 until the optimal solution does not appear in the optimal solution or reach the maximum iteration number. This paper sets the number of iterations, stops calculation, and outputs the current value, and then it is the optimal solution.

4. MICRO-GRID ENERGY CONTROL STRATEGY BASED ON CA AND ANT COLONY OPTIMIZATION

The distributed generation (DG) in micro-grid is divided into synchronous model DG and inverter model DG. Inverter model DG is a kind of active, reactive controlled power micro-power, which can realize flexible control of the voltage, phase angle, output power and so on, and has a converter topology in accordance with quality control device of power, it can respond quickly and achieve own regulation, especially it is suitable for micro-network [12].

The micro-grid load is relatively simple relative to the load in the traditional power grid, which are mainly linear loads. And the independent micro-grid in the case of insufficient power supply, it is necessary to remove some load, the loads are classified according to the following [11]:

Important load

This kind of load must ensure uninterrupted high-quality power supply, such as hospital.

Interruptible load

Under the premise of meeting the important load, then consider interrupting the load, such as ordinary lighting.

In Section 2.1, it is mentioned that switch between the interconnection and disconnection of the large power grid can be realized through the grid CA, so the connection status of the micro-grid at the next time can be determined by monitoring the power parameters of the grid CA, and determine whether the grid is in the isolated state. We can observe the island voltage limit of micro-grid to achieve, micro-island island voltage limit is shown in Table 1 [13].

Table 1. Voltage limit chart

voltage range	short-time voltage		overvoltage	
	phase voltage /kV	time limit /s	phase voltage /kV	time limit /s
upper limit	0.24-0.26	1	0.26	0.16
lower limit	0.11-0.2	2	0.11	0.16

In this paper, integrate the characteristics of the cellular automata described in Section 2.1, the micro-sources, loads, lines and so on are abstracted into the cells in the micro-grid, and their sets constitute a cell space, cell rules is used to simulate the operation condition of each component; give each cell a certain initial value, so that you can establish a running trace model that use CA simulate the sub-microgrid.

Whether the power change value Δf of cell and the voltage change value Δu exceed the frequency and voltage control range, we can determine the state of current cell accordingly. When the cell is out of range, it will fail, then the cell state value is set to "1"; if the control in range, it is already in normal operation condition or the cell can be return to normal state by fine tuning, then the cell state value is "0". The rated frequency is 50Hz in China, it should be maintained within the range of 50 ± 0.2Hz in normal operation; allowable offset of user power supply voltage is 10kV and below voltage level is ± 7%, micro-grid is composed of the 380V-10kV power supply voltage, this model assumes 380V power supply in this paper, so the allowable deviation of voltage should not exceed 20-25V [5].

Under the isolated network mode, the energy conservation equation of micro-source cell output power and the absorbed power of the load are [14-15]

$$Q = Q_L + \Delta Q \tag{14}$$

$$Q = Q_L = 3V_{PCC}^{2'}[(\omega' L)^{-1} - \omega' C] \tag{15}$$

In the formula, $\omega' = \omega + \Delta\omega$ -angular frequency at PCC in the island mode, $V_{PCC}' = V_{PCC} + \Delta V_{PCC}$ -phase voltage at PCC in the island mode. Q-active power and reactive power of micro-source output; QL-active power and reactive power of load; ΔQ-redundant active power and reactive power, ω- angular frequency at PCC; VPCC-Phase voltage at PCC; Under normal running state, the node CA monitors the running state of the micro-source, load and capacitor, bus bar CA monitors the bus voltage and the line CA monitors the line status. The emergency state is triggered by the node CA, the specific process is as follows:

1 When the node CA monitors the alarm signal: this paper mainly considers the problem of micro-source power shortage and load increase, CA can simply judge whether the alarm event can be quickly handled by the alarm unit. If the alarm unit can handle it, otherwise it will go to step 2.

2 The node CA sends a fault problem to the center CA and attaches current error list where the node CA is located, the center CA determines whether the faulty node is remedied according to the fault level, if the fault level is low, skip to step x, otherwise skip to step 3.

3 The center CA will send commands to each node CA, and instruct each node CA, line CA, bus CA to send the parameter table, and skip to step 4 after the collection of parameter table is complete.

4 The center CA calculates the parameter table based on the ant colony optimization and attempts to find one or more effective solution paths, these paths can "rescue" the faulty nodes and maintain voltage stability of bus line.

5 If the center CA can calculate this path, skip to step 6; otherwise, skip to step x.

6 Center CA establishes a simulation environment based on the current multi-microgrid state, and then the calculated path parameter table is sent to each simulation node CA, after the simulation node CA receive the parameter table, reset micro-source, load, capacitor state in accordance with the parameter table, and simulate the path.

7 After the reset state is complete, check whether each node CA, bus bar CA, and line CA cause fault alarm due to the status reset of each node CA, if any CA fails and alarmed to the center CA, skip to step 8. If the alarm does not occur, skips to step 9.

8 The center CA will discard the path and continue si mulating other paths until the last path ends.

9 Record the valid path, if the path simulation is not completed, continue to simulate, otherwise, skip to step 10.

10 The valid path table is mad e the best review, find an optimal path, and the simulation is over.

11 The center CA sends the optimal path parameters to each node CA, and each node receives the parameters and resets the node state, and start the rescue of the faulty node.

X. The center CA directly cuts the low-level load in accordance with the load of the failed node.

As shown in Fig. 3

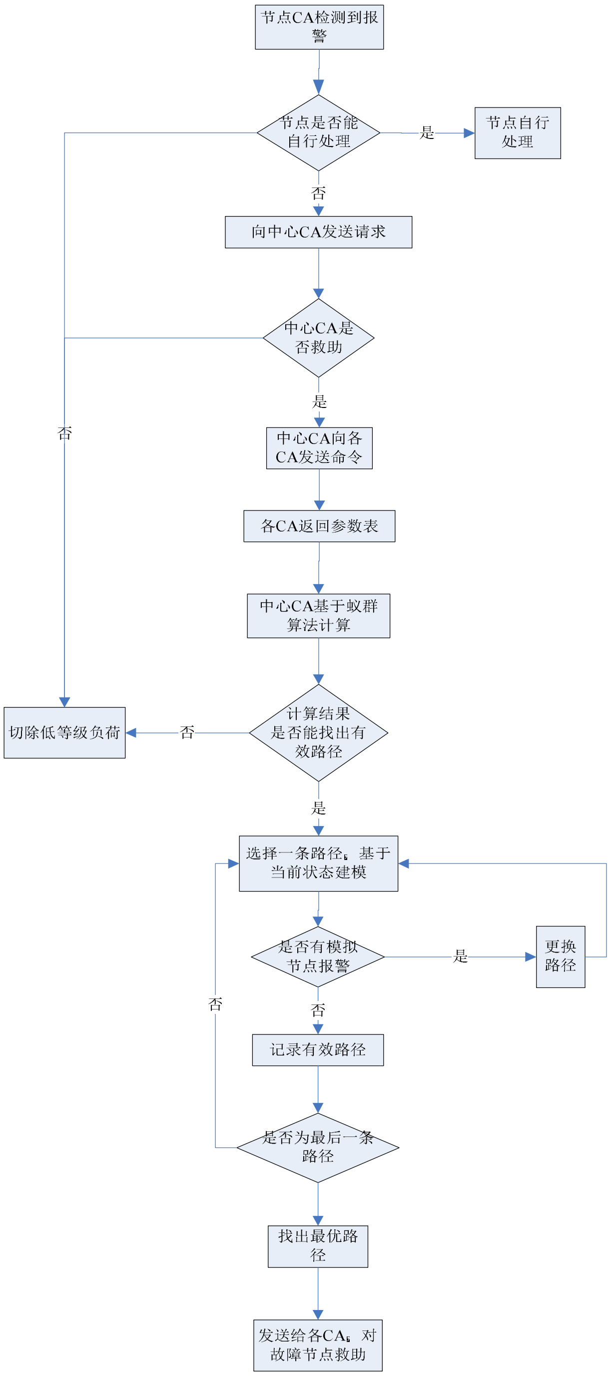

Fig. 3 flow chart of control strategy.

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