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Mathematical Model for Automatic Short-Circuit Calculation Based On Incidence Matrix in Coal Mine High-Voltage Grid

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Abstract

The mathematical model of automatic short-circuit calculation is proposed, that is directly used in coal mine high-voltage grid. The model combinates incidence matrix with short-circuit calculation in mine high-voltage grid. According to the connectivity of single-direction graph, the model describes the power supply relation matrix of branches node in coal mine high-voltage grid by the incidence matrix of bus node and branch node. The short-circuit calculation of all short-circuit points is achieved, according to the short-circuit matrix of three-phase and two-phase short-circuit current in all short circuit points given by the model. The analysis results show that the model can realize automatic short-circuit calculation accurately in coal mine high-voltage grid, and it provides a foundation for studying the performance of automatic short-circuit calculation and adaptive setting calculation of multiple fault operation mode.

Keywords*: incidence matrix; coal mine high-voltage grid, automatic short-circuit calculation, Topology self-learning*

1. Introduction

Coal mine high-voltage grid belongs to the distribution network, whose voltage is 6kV or 10kV. In distribution network, there often exists loop network or network structure supplied by multi powers at the same time. However, coal mine high-voltage grid has two powers supply generally, and the two powers run respectively, or one is used, while the other one is spare. The two powers are single-supply opening grid which is radial network structure. The system has more nodes, and it is a problem how to build a strongly adaptive network topology model to realize automatic short-circuit calculation in coal mine high-voltage grid, based on the characteristics of power supply network structure.

The literature [1-2] put forward a new fault short-circuit current calculation method, based on the structural features of distribution network that is radiation and little ring. It unlinks the looped network to the radial network, using branch impedance parameters of radial network to calculate short-circuit current directly. The literature [3] puts forward a short-circuit current calculation method of distribution network based on fault current compensation, and it uses phase methods to finish the short-circuit calculation based on the features of three-phase symmetric or asymmetric distribution system. The literature [4-5] put forward a short-circuit current calculation method based on variable structure mode that uses a zero impedance branch to simulate the circuit breaker. It makes use of variable structure and variable parameter analysis methods to calculate short-circuit current of circuit breaker, when there appears malfunction in the two sides of circuit breaker. The literature [6] puts forward two practical short-circuit current calculation methods, one is based on transfer impedance,while the other one is based on branch current, and which kinds of methods is used depending on the nature of the power system.

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Although the literature [1-6] propose a variety of short-circuit current calculation methods based on structural features of distribution network, there is no comprehensive analysis on realizing automatic short-circuit calculation by the topology model of distribution network.

The literature [7-8] use the breadth-first search to complete topology analysis according to the radical structure features of distribution networks, and then realize the automatic short-circuit calculation based on the topology model. The literature [9] carries out fast short-circuit calculation based on search algorithm, according to the characteristics of more power supply and less loop network. Through analyzing the single-direction topological graph of distribution network, the literature [10] realizes the optimal number of branch nodes based on search algorithm, and builds the incidence matrix of nodes and line segments according to the optimal number. Short-circuit calculation will be completed by using this incidence matrix in distribution network. When building the topology model of distribution network based on search algorithm in the literature [7-10], the linked list will be built to reflect topology structure. Topology analysis is achieved by processing linked list, so the recursive method is inevitable, which will lead to the more complexity of programming and maintenance, as well as the lower efficiency.

According to the characteristic of coal mine high-voltage grid, mathematic model of automatic short-circuit calculation based on incidence matrix is proposed in this paper. Network topology model about coal mine high-voltage grid is obtained though acquired incidence matrix of branch node and branch node. The model can easily complete topology identification in high coal mine high-voltage grid. And on the basis of the model, automatic short-circuit calculation can be realized. The model can adopt more connection nodes, having strong structure, clear analyzing process, and low complexity of maintenance, good expansibility, and higher efficiency.

2. Topology Model Based on Incidence Matrix in Coal Mine High-Voltage Grid

In this paper, the topology model of coal mine high-voltage grid is based on incidence matrix. Depending on the connecting relationship of electrical equipments, incidence matrix A and B of bus node and branch node can be obtained. According to the connectivity of unidirectional diagram, the incidence matrix E ($n \times n$) between the branch node and branch node can be obtained from incidence matrix A , B and the switching on-off state. Then, the topology analysis model based on incidence matrix is obtained. The specific model is as follows:

2.1. Incidence Matrix A and B of Bus Node and Branch Node

In coal mine high-voltage grid, taking substation bus as bus nodes and the branch connected with high-voltage outgoing line switch as branch nodes, if there are m bus nodes and n branch nodes, incidence matrix A ($m \times n$, taking bus node sequence number as the row number, taking branch node sequence number as column number) and incidence matrix B ($n \times m$,taking branch node sequence number as the row number, taking the bus node sequence number as column number) can be obtained by the connecting relationship of electrical equipments in coal mine high-voltage grid diagram. The steps are as follows:

（1）In the process of generating incidence matrix A, A_{ij} represent the i-th row and the j-th column element of matrix A. If the bus node which corresponds to the row number of row i is supplied by the branch node which corresponds to the column number of column j, then $F^T = \begin{bmatrix} F_1 & ... & F_i & ... & F_n \end{bmatrix}$, otherwise $1 \le i \le n$. Incidence matrix $A = \begin{bmatrix} A_{11} & A_{12} & ... & A_{1j} & ... & A_{1n} \\ A_{21} & A_{22} & ... & A_{2j} & ... & A_{2n} \\ ... & ... & ... & ... & ... & ... \\ A_{i1} & A_{i2} & ... & A_{ij} & ... & A_{in} \\ ... & ... & ... & ... & ... & ... \\ A_{m1} & A_{m2} & ... & A_{mj} & ... & A_{mn} \end{bmatrix}$;

（2）In the process of generating incidence matrix B, B_{ij} represents the i-th row and the j-th column element of matrix B. If the branch node which corresponds to the row number of row i is supplied by the bus node which corresponds to the column number of column j, then $B_{ij} = 1$, otherwise $B_{ij} = 0$. Incidence matrix $B = \begin{bmatrix} B_{11} & B_{12} & ... & B_{1j} & ... & B_{1m} \\ B_{21} & B_{22} & ... & B_{2j} & ... & B_{2m} \\ ... & ... & ... & ... & ... & ... \\ B_{i1} & B_{i2} & ... & B_{ij} & ... & B_{im} \\ ... & ... & ... & ... & ... & ... \\ B_{n1} & B_{n2} & ... & B_{nj} & ... & B_{nm} \end{bmatrix}$.

2.2. Ultimate Power Supply Incidence Matrix G of Branch Node and Branch Node

According to the connectivity of unidirectional diagram, the incidence matrix G between the branch node and branch node can be obtained. Matrix G can be described that a branch node is supplied by another branch node, G_{ij} represents the i-th row and the j-th column element of matrix G, if a branch node i is supplied by branch node j, then $G_{ij} = 1$, otherwise $G_{ij} = 0$; incidence matrix $G = \begin{bmatrix} G_{11} & G_{12} & ... & G_{1j} & ... & G_{1n} \\ G_{21} & G_{22} & ... & G_{2j} & ... & G_{2n} \\ ... & ... & ... & ... & ... & ... \\ G_{i1} & G_{i2} & ... & G_{ij} & ... & G_{in} \\ ... & ... & ... & ... & ... & ... \\ G_{n1} & G_{n2} & ... & G_{nj} & ... & G_{nn} \end{bmatrix}$. The specific steps are as follows:

(1) According to the state that the outgoing line switch is opening or closing on branch node, generating the switch state vector S of branch node, S contains n elements, and $S = \begin{bmatrix} S_1 & S_2 & ... & S_i & ... & S_n \end{bmatrix}, 1 \le i \le n$; in the state vector S, if the i-th element of corresponding switch state is closed, then $S_i = 1$, otherwise $S_i = 0$;

(2) n elements in switch state vector S and n elements of every row in the matrix A carried out the logic AND operation, the incidence matrix NA ($m \times n$) between the bus node and branch node can be obtained. $NA = \begin{bmatrix} A_{11}S_1 & A_{12}S_2 & ... & A_{1j}S_j & ... & A_{1n}S_n \\ A_{21}S_1 & A_{22}S_2 & ... & A_{2j}S_j & ... & A_{2n}S_n \\ ... & ... & ... & ... & ... & ... \\ A_{i1}S_1 & A_{i2}S_2 & ... & A_{ij}S_j & ... & A_{in}S_n \\ ... & ... & ... & ... & ... & ... \\ A_{m1}S_1 & A_{m2}S_2 & ... & A_{mj}S_j & ... & A_{mn}S_n \end{bmatrix}$; n elements in switch state vector S and n elements of every row in the matrix B carried out

the logic AND operation, the incidence matrix NB $(n \times m)$ between the branch node and bus node can be obtained. $NB = \begin{bmatrix} B_{11}S_1 & B_{12}S_1 & ... & B_{1j}S_1 & ... & B_{1m}S_1 \\ B_{21}S_2 & B_{22}S_2 & ... & B_{2j}S_2 & ... & B_{2m}S_2 \\ ... & ... & ... & ... & ... & ... \\ B_{i1}S_i & B_{i2}S_i & ... & B_{ij}S_i & ... & B_{im}S_i \\ ... & ... & ... & ... & ... & ... \\ B_{n1}S_n & B_{n2}S_n & ... & B_{nj}S_n & ... & B_{nm}S_n \end{bmatrix}$;

(3) According to the connectivity of unidirectional diagram, in this paper, by default multiplication operation of matrix element and matrix element is binary AND operation, and the addition operation of element and element is binary OR operation. The incidence matrix NB and the incidence matrix NA carry out multiply operation, and power supply incidence matrix C of the first level between original branch node and branch node will be obtained. So incidence matrix $C = NB \cdot NA$, C_{ij} represents the i-th row and the j-th column element of matrix C, then $C = \begin{bmatrix} C_{11} & C_{12} & ... & C_{1j} & ... & C_{1n} \\ C_{21} & C_{22} & ... & C_{2j} & ... & C_{2n} \\ ... & ... & ... & ... & ... & ... \\ C_{i1} & C_{i2} & ... & C_{ij} & ... & C_{in} \\ ... & ... & ... & ... & ... & ... \\ C_{n1} & C_{n2} & ... & C_{nj} & ... & C_{nn} \end{bmatrix}$, $C_{ij} = \sum_{k=1}^{m} B_{ik}S_i A_{kj}S_j$;

(4) Because adopting the unidirectional diagram structure,the relationship of power supply between the branch node i and the branch node i can not be reflected accurately while calculating the power supply incidence matrix C of branch node and branch node; therefore, a modified matrix M is required to modify the incidence matrix C, and the modified matrix M of branch nodes represents that each branch node i can be supplied by the branch node i. M_{ij} represent the i-th row and the j-th column element; $M = \begin{bmatrix} M_{11} & M_{12} & ... & M_{1j} & ... & M_{1n} \\ M_{21} & M_{22} & ... & M_{2j} & ... & M_{2n} \\ ... & ... & ... & ... & ... & ... \\ M_{i1} & M_{i2} & ... & M_{ij} & ... & M_{in} \\ ... & ... & ... & ... & ... & ... \\ M_{n1} & M_{n2} & ... & M_{nj} & ... & M_{nn} \end{bmatrix}$ and $M_{ij} = \begin{cases} 1, & \text{i} = \text{j} \\ 0, & \text{i} \neq \text{j} \end{cases}$. n elements in the S and n elements of each row in modified matrix M carry out the logic AND operation, then get the modified matrix NM of branch node and branch node,

$$NM = \begin{bmatrix} M_{11}S_1 & M_{12}S_2 & ... & M_{1j}S_j & ... & M_{1n}S_n \\ M_{21}S_1 & M_{22}S_2 & ... & M_{2j}S_j & ... & M_{2n}S_n \\ ... & ... & ... & ... & ... & ... \\ M_{i1}S_1 & M_{i2}S_2 & ... & M_{ij}S_j & ... & M_{in}S_n \\ ... & ... & ... & ... & ... & ... \\ M_{n1}S_1 & M_{n2}S_2 & ... & M_{nj}S_j & ... & M_{nn}S_n \end{bmatrix};$$

(5) The first level power supply incidence matrix of the branch node and branch node can be obtained according to matrix C and the modified matrix NM,

$$NC = C + NM = \begin{bmatrix} C_{11} + M_{11}S_1 & C_{12} + M_{12}S_2 & ... & C_{1j} + M_{1j}S_j & ... & C_{1n} + M_{1n}S_n \\ C_{21} + M_{21}S_1 & C_{22} + M_{22}S_2 & ... & C_{2j} + M_{2j}S_j & ... & C_{2n} + M_{2n}S_n \\ ... & ... & ... & ... & ... & ... \\ C_{i1} + M_{i1}S_1 & C_{i2} + M_{i2}S_2 & ... & C_{ij} + M_{ij}S_j & ... & C_{in} + M_{in}S_n \\ ... & ... & ... & ... & ... & ... \\ C_{n1} + M_{n1}S_1 & C_{n2} + M_{n2}S_2 & ... & C_{nj} + M_{nj}S_j & ... & C_{nn} + M_{nn}S_n \end{bmatrix};$$

(6) The matrix $D = NC * NC$, D_{ij} represents the i-th row and the j-th column element of matrix D, which is as follows:

$$D = \begin{bmatrix} D_{11} & D_{12} & \ldots & D_{1j} & \ldots & D_{1n} \\ D_{21} & D_{22} & \ldots & D_{2j} & \ldots & D_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ D_{i1} & D_{i2} & \ldots & D_{ij} & \ldots & D_{in} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ D_{n1} & D_{n2} & \ldots & D_{nj} & \ldots & D_{nn} \end{bmatrix} \text{ and } D_{ij} = \sum_{k=1}^{n} \left[\left(C_{ik} + M_{ik} S_k \right) \left(C_{kj} + M_{kj} S_j \right) \right];$$

(7) Comparing the matrix D and matrix NC, if they vary, then the matrix NC is replaced by matrix D, and repeat the step (6); otherwise, if the matrix D and matrix NC are the same, then the calculated matrix D is the power supply incidence matrix E of branch node and branch node, E_{ij} represent the i-th row and the j-th column element.

$$E = \begin{bmatrix} E_{11} & E_{12} & \ldots & E_{1j} & \ldots & E_{1n} \\ E_{21} & E_{22} & \ldots & E_{2j} & \ldots & E_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ E_{i1} & E_{i2} & \ldots & E_{ij} & \ldots & E_{in} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ E_{n1} & E_{n2} & \ldots & E_{nj} & \ldots & E_{nn} \end{bmatrix};$$

(8) Power branch node in coal mine high-voltage grid can be setted, and the power branch node is the branch node that is directly supplied by the superior department of power supply. Supposing the first l branch nodes are the power branch nodes among n branch nodes, then the power branch node is represented by the matrix L ($n \times 1$), $L^T = \left[L_1 \quad L_2 \quad \ldots \quad L_i \quad \ldots \quad L_n \right]$,where $L_i = \begin{cases} 1, & i \le l \\ 0, & i > l \end{cases}$, $1 \le i \le n$ .The matrix F ($n \times 1$) represents the nodes which need to complete the short circuit point calculation, $F^T = \left[F_1 \quad \ldots \quad F_i \quad \ldots \quad F_n \right]$,where $1 \le i \le n$. If $F_i = 1$, the corresponding branch node needs to finish the short-circuit calculation ; If $F_i = 0$, the corresponding branch node does not need the short-circuit calculation. i represent power supply line number controlled by the branch node, and $F = E \cdot L$, $F_i = \sum_{k=1}^{n} E_{ik} L_k$;

(9) n elements in matrix F and n elements of each row in matrix E carry out the login AND operation, and then the final incidence matrix G ($n \times n$) of power supply relationship among branch node and the branch node can be obtained.

$$G = \begin{bmatrix} E_{11}F_1 & E_{12}F_1 & \ldots & E_{1j}F_1 & \ldots & E_{1n}F_1 \\ E_{21}F_2 & E_{22}F_2 & \ldots & E_{2j}F_2 & \ldots & E_{2n}F_2 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ E_{i1}F_i & E_{i2}F_i & \ldots & E_{ij}F_i & \ldots & E_{in}F_i \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ E_{n1}F_n & E_{n2}F_n & \ldots & E_{nj}F_n & \ldots & E_{nn}F_n \end{bmatrix};$$

We can know the supply relationship among the branch node and the branch node by the final power supply incidence matrix G, and can provide a network topology analysis model for automatic short circuit calculation of coal mine high-voltage grid.

3. The Automatic Short-Circuit Calculation Algorithm Based on Network Topology Model

For the coal mine high–voltage grid , according to the supply line directly controlled by each branch node, resistance matrix R and reactance matrix X are established. The branch node number and the direct controlled supply line number are the same, and sequence number of power supply line is not only the row number, but also the column number in matrix X and matrix R. Assume that the resistance and reactance corresponding to the n supply line directly controlled by the n branch nodes are donated by $(R_1, R_2, ..., R_n)$ and $(X_1, X_2, ..., X_n)$ respectively, then matrix $R = \begin{bmatrix} R_1 & 0 & 0 & ... & 0 & 0 \\ 0 & R_2 & 0 & ... & 0 & 0 \\ 0 & 0 & R_3 & ... & 0 & 0 \\ ... & ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & R_{n-1} & 0 \\ 0 & 0 & 0 & ... & 0 & R_n \end{bmatrix}$, $X = \begin{bmatrix} X_1 & 0 & 0 & ... & 0 & 0 \\ 0 & X_2 & 0 & ... & 0 & 0 \\ 0 & 0 & X_3 & ... & 0 & 0 \\ ... & ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & X_{n-1} & 0 \\ 0 & 0 & 0 & ... & 0 & X_n \end{bmatrix}$.

Assume the matrix $W = [W_1 \quad W_2 \quad ... \quad W_i \quad ... \quad W_n]$, where $W_i = 1, 1 \le i \le n$; the system reactance matrix in the maximum operation mode is donated by $SX\max = [SX\max_1 \quad SX\max_2 \quad ... \quad SX\max_i \quad ... \quad SX\max_n]$, where $SX\max_i = \begin{cases} X\max, \text{if } F_i = 1 \\ 0, if\ F_i = 0 \end{cases}$, and $1 \le i \le n$, i is the power supply line number controlled by the branch node. The system reactance matrix in minimum operation mode is denoted by $SX\min = [SX\min_1 \quad SX\min_2 \quad ... \quad SX\min_i \quad ... \quad SX\min_n]$, where $SX\min_i = \begin{cases} X\min, \text{ if } F_i = 1 \\ 0,\ if\ F_i = 0 \end{cases}$, and $1 \le i \le n$. $X\max$ and $X\min$ are system reactance in maximum operation mode and minimum operation mode. According to the resistance matrix R, the reactance matrix X and the supply relation matrix G, we can obtain the total resistance matrix TR, the total reactance matrix in maximum operation mode $TX\max$ and the total reactance matrix in minimum operation mode $TX\min$ corresponding to all short-circuit points. The ith element of total resistance matrix TR is denoted by TR_i, the ith element of the matrix $TX\max$ is denoted by $TX\max_i$ and the ith element of the matrix of $TX\min$ is denoted by $TX\min_i$. i represents the short-circuit point corresponding to the i-th branch node, TR_i denotes the total resistance of i-th short-circuit point, $TX\max_i$ denotes the total reactance of i-th short-circuit point in the maximum operation mode, $TX\min_i$ denotes the total reactance of i-th short-circuit point in minimum operation mode. Then :

$$TR=\begin{bmatrix}TR_1\\TR_2\\...\\TR_i\\...\\TR_n\end{bmatrix}=GRW^T=\begin{bmatrix}E_{11}F_1 & E_{12}F_1 & ... & E_{1j}F_1 & ... & E_{1n}F_1\\E_{21}F_2 & E_{22}F_2 & ... & E_{2j}F_2 & ... & E_{2n}F_2\\... & ... & ... & ... & ... & ...\\E_{i1}F_i & E_{i2}F_i & ... & E_{ij}F_i & ... & E_{in}F_i\\... & ... & ... & ... & ... & ...\\E_{n1}F_n & E_{n2}F_n & ... & E_{nj}F_n & ... & E_{nn}F_n\end{bmatrix}\begin{bmatrix}R_1 & 0 & 0 & ... & 0 & 0\\0 & R_2 & 0 & ... & 0 & 0\\0 & 0 & R_3 & ... & 0 & 0\\... & ... & ... & ... & ... & ...\\0 & 0 & 0 & ... & R_{n-1} & 0\\0 & 0 & 0 & ... & 0 & R_n\end{bmatrix}\begin{bmatrix}W_1\\W_2\\...\\W_i\\...\\W_n\end{bmatrix}=\begin{bmatrix}\sum_{k=1}^{n}E_{1k}F_1R_kW_k\\\sum_{k=1}^{n}E_{2k}F_2R_kW_k\\...\\\sum_{k=1}^{n}E_{ik}F_iR_kW_k\\...\\\sum_{k=1}^{n}E_{nk}F_nR_kW_k\end{bmatrix}$$

$$TX\max=\begin{bmatrix}TX\max_1\\TX\max_2\\...\\TX\max_i\\...\\TX\max_n\end{bmatrix}=GXW^T+SX\max=\begin{bmatrix}(\sum_{k=1}^{n}E_{1k}F_1X_kW_k)+SX\max_1\\(\sum_{k=1}^{n}E_{2k}F_2X_kW_k)+SX\max_2\\...\\(\sum_{k=1}^{n}E_{ik}F_iX_kW_k)+SX\max_i\\...\\(\sum_{k=1}^{n}E_{nk}F_nX_kW_k)+SX\max_n\end{bmatrix}$$

$$TX\min=\begin{bmatrix}TX\min_1\\TX\min_2\\...\\TX\min_i\\...\\TX\min_n\end{bmatrix}=GXW^T+SX\min=\begin{bmatrix}(\sum_{k=1}^{n}E_{1k}F_1X_kW_k)+SX\min_1\\(\sum_{k=1}^{n}E_{2k}F_2X_kW_k)+SX\min_2\\...\\(\sum_{k=1}^{n}E_{ik}F_iX_kW_k)+SX\min_i\\...\\(\sum_{k=1}^{n}E_{nk}F_nX_kW_k)+SX\min_n\end{bmatrix}$$

While calculating the TR, $TX\max$, $TX\min$, this paper adopts the decimal arithmetic operation between the matrix elements and matrix elements. Assume three phase short-circuit current matrix in maximum operation mode is denoted by $I_{\max}^{(3)}$, and the two phase short-circuit current matrix in minimum operation mode is denoted by $I_{\min}^{(2)}$, the average voltage of short-circuit line in the high-voltage grid is denoted by U. The i-th element of the matrix $I_{\max}^{(3)}$ is denoted by $I_{\max i}^{(3)}$, the ith element of the matrix $I_{\min}^{(2)}$ is denoted by $I_{\min i}^{(2)}$. i denotes the short-circuit point corresponding to the ith branch node, $I_{\max i}^{(3)}$ denotes three phase short-circuit current of i-th short-circuit point, $I_{\min i}^{(2)}$ denotes two phase short-circuit current of i-th short-circuit point ,then

$(I_{\max}^{(3)})^T=\begin{bmatrix}I_{\max 1}^{(3)} & I_{\max 2}^{(3)} & ... & I_{\max i}^{(3)} & ... & I_{\max n}^{(3)}\end{bmatrix}$, $(I_{\min}^{(2)})^T=\begin{bmatrix}I_{\min 1}^{(2)} & I_{\min 2}^{(2)} & ... & I_{\min i}^{(2)} & ... & I_{\min n}^{(2)}\end{bmatrix}$. And

$$I_{\max i}^{(3)}=\frac{U}{\sqrt{3}\sqrt{TR_i^2+TX\max_i^2}}=\frac{U}{\sqrt{3}\sqrt{(\sum_{k=1}^{n}E_{ik}F_iR_kW_k)^2+((\sum_{k=1}^{n}E_{ik}F_iX_kW_k)+SX\max_i)^2}},$$

$$I_{\min i}^{(2)}=\frac{U}{2\sqrt{TR_i^2+TX\min_i^2}}=\frac{U}{2\sqrt{(\sum_{k=1}^{n}E_{ik}F_iR_kW_k)^2+((\sum_{k=1}^{n}E_{ik}F_iX_kW_k)+SX\max_i)^2}}.$$

4. Algorithm Analysis

We will finish the short calculation of all the short-circuit points in the coal mine high-voltage grid shown in Figure 1, using the automatic short-circuit calculation method based on incidence matrix proposed in this paper. Assuming Figure 1 is a coal mine high-voltage grid diagram. The state of branch node with a black block is open, and the state of unfilled block is closing. Bus node number and the branch node number is shown in Figure 1.The steps are as follows:

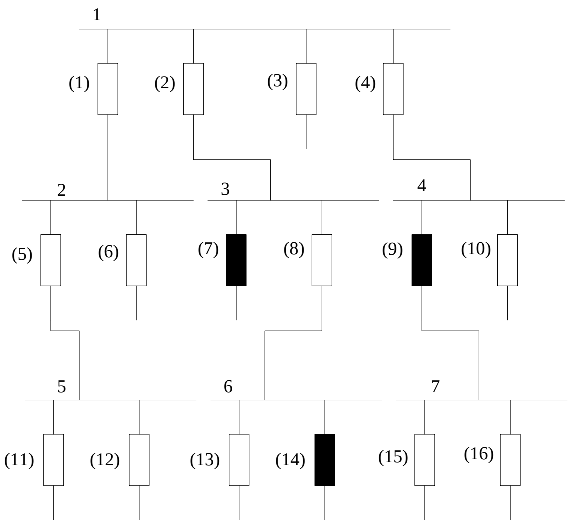

Figure 1. Coal Mine High-Voltage Grid Diagram

(1) Calculate the incidence matrix A and B,

$$A=\begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\ 1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0 \end{bmatrix}, B=\begin{bmatrix} 1&0&0&0&0&0&0\\ 1&0&0&0&0&0&0\\ 1&0&0&0&0&0&0\\ 1&0&0&0&0&0&0\\ 0&1&0&0&0&0&0\\ 0&1&0&0&0&0&0\\ 0&0&1&0&0&0&0\\ 0&0&1&0&0&0&0\\ 0&0&0&1&0&0&0\\ 0&0&0&1&0&0&0\\ 0&0&0&0&1&0&0\\ 0&0&0&0&1&0&0\\ 0&0&0&0&0&1&0\\ 0&0&0&0&0&1&0\\ 0&0&0&0&0&0&1\\ 0&0&0&0&0&0&1 \end{bmatrix};$$

(2) Calculate the switch state matrix S,

$$S=\begin{bmatrix}1&1&1&1&1&1&0&1&0&1&1&1&1&0&1&1\end{bmatrix};$$

(3) Calculate matrix NA and NB,

$$NA=\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix},\quad NB=\begin{bmatrix}
1&0&0&0&0&0&0\\
1&0&0&0&0&0&0\\
1&0&0&0&0&0&0\\
1&0&0&0&0&0&0\\
0&1&0&0&0&0&0\\
0&1&0&0&0&0&0\\
0&0&0&0&0&0&0\\
0&0&1&0&0&0&0\\
0&0&0&0&0&0&0\\
0&0&0&1&0&0&0\\
0&0&0&0&1&0&0\\
0&0&0&0&1&0&0\\
0&0&0&0&0&1&0\\
0&0&0&0&0&0&0\\
0&0&0&0&0&0&1\\
0&0&0&0&0&0&1
\end{bmatrix};$$

(4) Calculate incidence matrix C,

$$C=NB*NA=\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix};$$

(5) Calculate incidence matrix NM,

$$NM=\begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1
\end{bmatrix};$$

(6) Calculate incidence matrix NC ,

$$NC = C + NM = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix};$$

(7) Calculate incidence matrix D ,

$$D = NC * NC = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix};$$

(8) Calculate incidence matrix E,

$$E=\begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&1&0&0&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&1&0&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&0&1&0&0&0&0\\
0&1&0&0&0&0&0&1&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1
\end{bmatrix};$$

(9) Calculate matrix L and F,assuming in coal mine high-voltage grid shown in Figure 1, power branch nodes are {(1),(2),(3),(4)},then $L^T=\begin{bmatrix}1&1&1&1&0&0&0&0&0&0&0&0\end{bmatrix}$,matrix $F^T=(E\cdot L)^T=\begin{bmatrix}1&1&1&1&1&1&0&1&0&1&1&1&1&0&0&0\end{bmatrix}$;

(10) Calculate incidence matrix G

$$G=\begin{bmatrix}
1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
1&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&1&0&0&0&0&0&1&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&1&0&0&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&1&0&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&0&1&0&0&0&0\\
0&1&0&0&0&0&0&1&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix};$$

(11) Calculate total resistance matrix TR and total reactance matrix $TX\max$ in the maximum operation mode and total reactance matrix $TX\min$ in the minimum operation mode, then:

$$TR = GRW^T = \begin{bmatrix} R_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & R_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & R_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & R_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ R_1 & 0 & 0 & 0 & R_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ R_1 & 0 & 0 & 0 & 0 & R_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & R_2 & 0 & 0 & 0 & 0 & 0 & R_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & R_4 & 0 & 0 & 0 & 0 & 0 & R_{10} & 0 & 0 & 0 & 0 & 0 & 0 \\ R_1 & 0 & 0 & 0 & R_5 & 0 & 0 & 0 & 0 & 0 & R_{11} & 0 & 0 & 0 & 0 & 0 \\ R_1 & 0 & 0 & 0 & R_5 & 0 & 0 & 0 & 0 & 0 & 0 & R_{12} & 0 & 0 & 0 & 0 \\ 0 & R_2 & 0 & 0 & 0 & 0 & 0 & R_8 & 0 & 0 & 0 & 0 & R_{13} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} = \begin{vmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_1 + R_5 \\ R_1 + R_6 \\ 0 \\ R_2 + R_8 \\ 0 \\ R_4 + R_{10} \\ R_1 + R_5 + R_{11} \\ R_1 + R_5 + R_{12} \\ R_2 + R_8 + R_{13} \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

Simultaneously,

$$TX\max = GXW^T + SX\max = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_1 + X_5 \\ X_1 + X_6 \\ 0 \\ X_2 + X_8 \\ 0 \\ X_4 + X_{10} \\ X_1 + X_5 + X_{11} \\ X_1 + X_5 + X_{12} \\ X_2 + X_8 + X_{13} \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} X\max \\ X\max \\ X\max \\ X\max \\ X\max \\ X\max \\ 0 \\ X\max \\ 0 \\ X\max \\ X\max \\ X\max \\ X\max \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} X_1 + X\max \\ X_2 + X\max \\ X_3 + X\max \\ X_4 + X\max \\ X_1 + X_5 + X\max \\ X_1 + X_6 + X\max \\ 0 \\ X_2 + X_8 + X\max \\ 0 \\ X_4 + X_{10} + X\max \\ X_1 + X_5 + X_{11} + X\max \\ X_1 + X_5 + X_{12} + X\max \\ X_2 + X_8 + X_{13} + X\max \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

$$TX\min = GXW^T + SX\min = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_1 + X_5 \\ X_1 + X_6 \\ 0 \\ X_2 + X_8 \\ 0 \\ X_4 + X_{10} \\ X_1 + X_5 + X_{11} \\ X_1 + X_5 + X_{12} \\ X_2 + X_8 + X_{13} \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} X\min \\ X\min \\ X\min \\ X\min \\ X\min \\ X\min \\ 0 \\ X\min \\ 0 \\ X\min \\ X\min \\ X\min \\ X\min \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} X_1 + X\min \\ X_2 + X\min \\ X_3 + X\min \\ X_4 + X\min \\ X_1 + X_5 + X\min \\ X_1 + X_6 + X\min \\ 0 \\ X_2 + X_8 + X\min \\ 0 \\ X_4 + X_{10} + X\min \\ X_1 + X_5 + X_{11} + X\min \\ X_1 + X_5 + X_{12} + X\min \\ X_2 + X_8 + X_{13} + X\min \\ 0 \\ 0 \\ 0 \end{bmatrix}.$$

(12) Calculate the three-phase short-circuit current matrix $I_{\max}^{(3)}$ and two-phase short-circuit current matrix $I_{\min}^{(2)}$, then:

$$I_{\max}^{(3)}=\begin{bmatrix} \dfrac{U}{\sqrt{3}\sqrt{(X_1+X\max)^2+R_1^{\,2}}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_2+X\max)^2+R_2^{\,2}}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_3+X\max)^2+R_3^{\,2}}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_4+X\max)^2+R_4^{\,2}}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_1+X_5+X\max)^2+(R_1+R_5)^2}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_1+X_6+X\max)^2+(R_1+R_6)^2}} \\ 0 \\ \dfrac{U}{\sqrt{3}\sqrt{(X_2+X_8+X\max)^2+(R_2+R_8)^2}} \\ 0 \\ \dfrac{U}{\sqrt{3}\sqrt{(X_4+X_{10}+X\max)^2+(R_4+R_{10})^2}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_1+X_5+X_{11}+X\max)^2+(R_1+R_5+R_{11})^2}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_1+X_5+X_{12}+X\max)^2+(R_1+R_5+R_{12})^2}} \\ \dfrac{U}{\sqrt{3}\sqrt{(X_2+X_8+X_{13}+X\max)^2+(R_2+R_8+R_{13})^2}} \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

$$I_{\min}^{(2)} = \begin{bmatrix} \dfrac{U}{2\sqrt{(X_1 + X\min)^2 + R_1^{\,2}}} \\ \dfrac{U}{2\sqrt{(X_2 + X\min)^2 + R_2^{\,2}}} \\ \dfrac{U}{2\sqrt{(X_3 + X\min)^2 + R_3^{\,2}}} \\ \dfrac{U}{2\sqrt{(X_4 + X\min)^2 + R_4^{\,2}}} \\ \dfrac{U}{2\sqrt{(X_1 + X_5 + X\min)^2 + (R_1 + R_5)^2}} \\ \dfrac{U}{2\sqrt{(X_1 + X_6 + X\min)^2 + (R_1 + R_6)^2}} \\ 0 \\ \dfrac{U}{2\sqrt{(X_2 + X_8 + X\min)^2 + (R_2 + R_8)^2}} \\ 0 \\ \dfrac{U}{2\sqrt{(X_4 + X_{10} + X\min)^2 + (R_4 + R_{10})^2}} \\ \dfrac{U}{2\sqrt{(X_1 + X_5 + X_{11} + X\min)^2 + (R_1 + R_5 + R_{11})^2}} \\ \dfrac{U}{2\sqrt{(X_1 + X_5 + X_{12} + X\min)^2 + (R_1 + R_5 + R_{12})^2}} \\ \dfrac{U}{2\sqrt{(X_2 + X_8 + X_{13} + X\min)^2 + (R_2 + R_8 + R_{13})^2}} \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

According to the coal mine high-voltage grid diagram, the short-circuit calculation of all fault branch nodes is achieved by hands, and the calculation results by hands are consistent with the mathematic model of automatic short-circuit calculation based on incidence matrix in this paper. Therefore, the mathematic model of automatic short-circuit calculation based on incidence matrix in coal mine high-voltage grid can effectively realize automatic short-circuit calculation of all short-circuit points in coal mine high-voltage grid.

5. Conclusions

In coal mine high-voltage grid, the existing automatic calculation methods are mainly based on breadth first search or depth first search to implement topology learning, which needs to adopt the recursive method. Therefore, it has more complexity of programming and maintenance, as well as lower efficiency.

The mathematic model of automatic short-circuit calculation in coal mine high-voltage grid is proposed based on incidence matrix in this paper, which combines incidence matrix with short-circuit calculation algorithm. According to the connectivity of unidirectional diagram, the supply relation matrix of coal mine high-voltage grid is descried by the incidence matrix between the bus node and branch node and the on-off state of switch. The model can propose the short-circuit matrix of three-phase and two-phase short current in all short points, and the short calculation results of all short points will be obtained.

The mode analysis results show that the model can realize automatic short-circuit calculation accurately in coal mine high-voltage grid, and it provides a foundation for studying the performance of automatic short-circuit calculation and adaptive setting calculation of multiple fault operation mode. Compared with the existing automatic short calculation algorithm, the model can adopt complex connection modes, having strong structure, clear analyzing process, low complexity of maintenance, good expansibility, and higher efficiency.

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References

[1] G.-C. Cao, J.-H. Song and Z. Liu, "A New Method to Calculate Short Circuits in Weakly Meshed Distribution and Subtransmission Networks", Proceedings of the CSEE, vol. 17, no. 3, **(1997)**, pp. 207 - 210.
[2] J.-D. Jiang, X. Zhang and S.-G. Wang, "Three-phase Shunt APF Adopting Low-order Harmonics Zero-steady-error Control Strategy", Automation of electric power systems,, vol. 34,no. 12, **(2010),** pp. 44-47.
[3] H. Zhang, "A Practical Algorithm of Short Circuit Calculation for Radial Distribution Networks", Power System Technology, vol. 25, no. 12, **(2001)**, pp. 38-41.
[4] Q.-Y. Luo and X.-M. Li, "A Novel Algorithm of Short-Circuit Current With Variable Structure Model", Proceeding s of the CSEE, vol. 25, no. 1, **(2005)**, pp. 77-78.
[5] Y.-Z. Xu and Q.-J. Liu, "Electrical Equipment Short-circuit Current Calculation Based on Variable Structure Model", Jiangsu Electrical Engineering, vol. 29, no. 2, **(2010)**, pp. 50-53.
[6] X.-D. Yu, S.-T. Zhou and G.-P. Yu, "Discussion on Two Practical Methods for Fault Current Calculation", Proceedings of the CSU –EPSA, vol. 18, no. 4, **(2006)**, pp. 108-112.
[7] R.-F. Che, R.-J. Li and Y.-Z. Li, "Improvement and Implementation of the Inner Data Transmission Structure in Area Stability Control Device", Automation of electric power systems, vol. 25, no. 24, **(2001)**, pp . 22-25.
[8] R.-F. Che, S.-Z. Bai and R.-J. Li, "Implementation of Topology Analysis and Short Circuit Calculation for Distribution Systems", Proceedings of the CSU -EPSA, vol. 14, no. 6, **(2002)**, pp. 77-81.
[9] L.-T. Wong, Y.-M. Wang, K.-P.Liu and H.-L. Zhou, "Multi-Power Short Circuit Calculation on Middle and Lower Voltage Distribution Grid's Structure Characteristics", Transactions of China Electrotechnical Society, vol. 25, no. 10, **(2010)**, pp. 150-157.
[10] Y.-S. Wang and P. Wang, "New Algorithm for Calculating Distribution System Short-Circuit Fault", Power System Technology, vol. 3, no. 6, **(1999)**, pp. 8-14.

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