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Parallel Topology Analysis Method of Coal Mine High Voltage Power Grids based on Genetic Algorithm

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Abstract

The existing topology analysis method based on correlation matrix for coal mine high voltage power grids has the problems of high time complexity and low computational efficiency. By introducing the first-come first-serve parallel scheduling algorithm into the above topology analysis method, the computational efficiency can be improved to a certain extent. Based on this, this paper further proposes an adaptive topology analysis algorithm for coal mine high voltage power grid based on the successive comparison method and genetic algorithm, which can further improve the parallel scheduling efficiency of topology analysis for coal mine high voltage power grids. The simulation results show that the adaptive topology analysis algorithm for coal mine high voltage power grid based on genetic algorithm can improve the computational efficiency and reduce the time overhead better than other algorithms can.

Keywords: parallel computing; topology analysis; coal mine high voltage power grid; time overhead

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1. Introduction

The online setting system for relay protection of high-voltage power grids in coal mines has high requirements for fixed-value calculation of time overhead. When the operation mode of high-voltage power grid in coal mine changes, the online setting system of relay protection in coal mine high voltage grids should complete topology analysis of high voltage coal mine power networks in as little time as possible. According to the results of topology analysis, the automatic short-circuit calculation and automatic tuning calculation are completed, so that the new relay protection setting scheme can be obtained as soon as possible, and the online intelligent management of high-voltage grids of coal mines can be realized. Therefore, on the premise of ensuring the setting accuracy of relay protection, the time overhead of topology analysis is reduced as much as possible, and the efficiency of topology analysis and calculation of high voltage power grids in coal mines is improved. This is the first problem to be solved in the online setting system for relay protection of coal mine high voltage power grids.

In literature [1], an online parallel setting calculation method that effectively improves the efficiency of large power grid tuning calculation was proposed. In literature [2], an online verification and early warning system based on multi-agent technology was established, and the verification was completed based on multi-thread parallel cooperation. In literature [3], the calculation speed of online setting was improved by using window technology in view of the influence of local changes on the protection setting. In literature [4], taking the development of smart grid as an opportunity, a multi-agent technology was used to design a smart grid relay protection online tuning system to complete online tuning calculation. In literature [5], a new method for online setting of relay protection setting was proposed. It relies on the fault information system or fixed value setting communication unit to build the set value remote automatic setting system and uses the remote delivery device fixed value modification command to achieve online tuning. In literature [6], based on the setting value calculation system of relay protection and the function of remote modification and setting of relay protection, a scheme of online management and control of setting value of relay protection was proposed. It improves the automation

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level of relay protection management and operation and maintenance personnel. In literature [7], a network partitioning algorithm was chosen to decompose the network into smaller sub-networks, greatly increasing the calculation speed, and it was verified by an example.

As can be seen from the above literature, parallel computing technology has been widely used in traditional power systems to improve the calculation efficiency of relay protection automatic setting systems. Introducing parallel computing technology in coal mine high voltage grid relay protection online setting systems to improve calculation efficiency is a problem to be solved.

In literature [8], an adaptive topology analysis method for coal mine high-voltage power grid based on correlation matrix was proposed. The adaptive topology analysis of coal mine high-voltage power network under various operation modes was realized. However, the time complexity and computational overhead of the method were high. In literature [9], a short-circuit calculation method of coal mine high-voltage power grid based on the first-come first-serve and correlation matrix was proposed. The parallel scheduling model of first-come first-serve is introduced into the short-circuit calculation of coal mine high-voltage power grids, effectively improving the efficiency of topology analysis of coal mine high-voltage power grids.

Based on the above research, this paper will optimize the parallel scheduling strategy according to the structural characteristics of coal mine high voltage power grids. Based on the existing parallel topology method of coal mine high-voltage power grids, a parallel-based scheduling model based on the successive comparison method and genetic algorithm is proposed to further improve the efficiency of topology analysis and provide a research foundation for realizing the online setting system of relay protection for coal mine high-voltage power grids.

2. Parallel Network Topology Analysis Algorithm based on Successive Comparison Method and Genetic Algorithm

The existing parallel network topology analysis method based on first-come first-serve [9] can reduce the time overhead of topology analysis of high voltage grids in coal mines to a certain extent, but it will encounter the problem of different thread end time. This will reduce the parallel computing efficiency. Therefore, an adaptive parallel network topology analysis algorithm based on the successive comparison method and genetic algorithm is proposed to improve computing efficiency.

2.1. Secondary Scheduling Group Index

Different local coal mine high-voltage grid diagrams corresponding to the branch node set AS_i contain different numbers of branch nodes and different grid structures, so the time overhead of completing the topology analysis between nodes and branches in each set is also different. Therefore, determining what kind of index will make reasonable secondary dispatching grouping for the existing high-voltage grid diagrams of local coal mines is a problem to be solved.

2.1.1. Number Indicator of High Voltage Switches $RuleN$

The number indicator of high voltage switches in different sets can reflect the corresponding topology analysis time of each set to a certain extent. Therefore, the number of high voltage switches in the set (excluding tie switches) is taken as an indicator of the secondary scheduling group, expressed as $RuleN$. Based on the number of high voltage switches in each set, the network topology analysis is completed, and the implementation process is relatively simple. However, there is a nonlinear relationship between the corresponding topology analysis time of each set and the number of high voltage switches in the set. Therefore, scheduling grouping based on the number of high voltage switches in each set will lead to some deviation in the result of grouping, which will ultimately directly affect the time overhead of parallel topology analysis.

2.1.2. Historical Topology Analysis Time Index $RuleHT$

In order to solve the problem of index $RuleN$, this paper presents that the historical topological analysis time of high voltage grid diagrams of local coal mines is used as an index of secondary dispatch grouping, expressed as $RuleHT$. According to the high-voltage power supply system topology analysis algorithm [10], as long as the number of branch nodes, the number of power supply systems, the maximum number of busbar, the number of bus nodes, and the number of contact switch nodes in the power supply system diagram are the same, the time overhead for performing topology analysis using the above topology analysis algorithm is also the same.

Therefore, based on the above principle, according to the number of branch nodes, the series of power supply system, the maximum segment number of busbar, the number of bus nodes, and the number of contact switch nodes, the historical time overhead table PTS of local high voltage power supply systems in common use can be constructed in advance. There are six fields in the history time overhead table: the number of branch nodes, the series of power supply system, the maximum number of bus segments, the number of bus nodes, the number of contact switch nodes, and the weight of time overhead. In the history time overhead table PTS of high voltage power supply systems in coal mines, the history time overhead of topological analysis of local high voltage power supply systems in coal mines has been saved in advance. The following scheduling packet algorithm will schedule packets according to the indexes $RuleN$ and $RuleHT$, and the topological analysis time calculated according to the result of the packet will be compared and analyzed to determine a grouping index with better performance from the above indexes. This provides the research foundation for the realization of parallel calibration systems of coal mine high voltage networks.

2.2. Scheduling Grouping Algorithm based on Successive Comparison Method

According to the historical time overhead table PTS, the historical topological analysis time of all sets AS_i corresponding to the local high voltage power supply system diagram of coal mines can be queried, and then the historical topology analysis time obtained from the query can be taken as the grouping basis. The historical topological analysis time of each local coal mine high-voltage power supply system diagram is put into the set P, each corresponding element in the set P is represented as K_i, and then the sum of all elements in P is $R = \sum_{i=1}^{n} K_i$. Then, based on the successive comparison technique, the branch sets corresponding to some elements of the set P are added to the h queue Q_j respectively, where $1 \leq j \leq h$ and $h \leq m$. The specific steps are as follows:

Step 1 Allow the number of established threads to be represented in m.

Step 2 The average topological analysis time

$$AVG = \left[\frac{R}{m}\right] = \left[\frac{\sum_{i=1}^{n} K_i}{m}\right]$$

per thread, and it is reordered by the corresponding element $K_i (1 \leq i \leq n)$ in the collection P in order from large to small. The ordered elements are added to queue QS in order from large to small to set the initial value of j to 1. One element is extracted from queue QS according to the principle of first-in first-out, and the element is added to queue Q_j.

Step 3 Extract an element from the queue QS in accordance with the first-in first-out principle, which is represented by G, and the topological analysis time that the element contains is expressed in D. Assume that the total number of topological analysis times contained by all the elements saved in queue Q_j is expressed in F_j. If $(F_j + D) > AVG$, the element G is added to queue QT and step 4 is performed; if $(F_j + D) > AVG$, the element G is added to queue Q_j and step 4 is performed.

Step 4 If there is still an element in queue QS that has not been taken out, perform step 3; if all the elements in queue QS have been taken out, perform step 5.

Step 5 If the queue QT is not empty, add the value of j by 1, add all the elements in the queue QT in the first-in first-out order to the queue QS, take an element from the queue QS according to the first-out principle, add this element to the queue Q_j, and perform step 3; if queue QT is empty, assign the value of Q_j to h and perform step 6.

Step 6 If $h < m$, assign the value of h to m, and delete queue $Q_1, \cdots, Q_h$. If h and m are equal, several elements in the set P are added to the h queue Q_j respectively, $1 \leq j \leq h$. Then, the branch sets corresponding to some elements in the set P are added to the h queue Q_j respectively.

2.3. Scheduling Grouping Algorithm based on Genetic Algorithm

Genetic algorithm [11-12] is a kind of bionic algorithm that is used to solve the optimization problem. It finds the optimal solution by optimizing a certain number of initial solutions. In this paper, a parallel topology analysis algorithm based on genetic algorithm is constructed and can save time overhead effectively. The specific process is as follows:

According to the historical time overhead table PTS, the historical topological analysis time of all local coal mine high-voltage power supply system diagrams corresponding to set AS_i can be obtained. Then, based on the historical topology analysis time obtained from the query (or the number of high-voltage switches contained in each local coal mine high-voltage power supply system), the historical topological analysis time of each local coal mine high-voltage power supply system diagram (the number of high-voltage switches contained in each local coal mine high-voltage power supply system) is put into the set P. Based on genetic algorithm, several elements of set P are added to V queue Q_j respectively, where $1 \leq j \leq V$. The specific steps are as follows:

Step 1 Allow the number of established threads to be V. The historical topological analysis time (or the number of high-voltage switches) contained in the set P is represented as PN_i, $1 \leq i \leq n$. The genetic algorithm evolutionary algebra $UD = 0$.

Step 2 The groups corresponding to each element in the set P are represented by X_i, and the elements in the set P need to be divided into a group of V respectively and added to the V queue Q_j, where $1 \leq X_i \leq V$, $1 \leq i \leq n$. If an element in the set P is divided into the j^{th} group, the corresponding group is $X_i = j$, and then the corresponding grouping j and the corresponding element in the collection P will be added to the queue Q_j.

Step 3 The grouped individuals corresponding to each element in the set P are represented by Y_k, $Y_k = [X_1, X_2, \cdots, X_i, \cdots, X_n]$, where X_i is a random integer. $1 \leq X_i \leq V$, $1 \leq i \leq n$, and h individuals Y_k are randomly generated according to the individual definition, where $1 \leq k \leq h$, $h \geq 50$. The h individual Y_k is added to the set W. For each individual in the set W, perform step 4.

Step 4 A matrix Z_k is generated according to the individual Y_k, $Z_k = \left[Z_{k1} \cdots Z_{kj} \cdots Z_{kv}\right]$. In the initial case, the value of each element in the matrix Z_k is equal to 0. The value of i is set to 1, and for each element X_i in the individual Y_k, perform step 5.

Step 5 If $X_i = j$, then add the value of PN_i and Z_{kj} to get the value $TEMP$, and then give the value of $TEMP$ to Z_{kj}. Adding the value of i by 1, if $i > n$, execute step 6; if $i \leq n$, repeat the value of step 5.

Step 6 For each individual Y_k, calculate the fitness $f(Y_k)$ as

$$\frac{\sum_{j=1}^{V} \left| Z_{kj} - \left(\frac{\sum_{j=1}^{V} Z_{kj}}{V} \right) \right|^2}{V - 1}$$

Step 7 Adding the value of genetic algorithm evolutionary algebra UD to 1, if there is an individual fitness $f(Y_k) \leq 0.5$in the set W or if UD is greater than 500, execute step 8; otherwise, according to the fitness $f(Y_k)$ of each individual in the set W, complete individual elimination, crossover, and variation. The set W is set to be empty, all the individuals in the set BW are added to the set W, and the set WB is set to null. For each individual Y_k in the set W, perform step 4.

Step 8 For each element X_i of an individual Y_k in the set W that satisfies the condition, perform step 9.

Step 9 If $X_i = j$, the branch collection of the X_i corresponding elements will be added to the queue Q_j.

2.4. Parallel Topology Analysis Algorithm based on Packet Scheduling

Create h new idle threads, and h new idle threads are added to the queue QC of idle threads. The corresponding topological analysis parallel computation is completed for the corresponding branch set of the elements stored in each queue Q_j. The specific steps are as follows:

Step 1 Create h new idle threads. h new idle threads are added to the queue QC of idle threads, and the initial value of j is set to 1.

Step 2 Take an idle thread from the idle thread queue QC, bind queue Q_j to a newly created idle thread, set the thread as a busy thread, and add it to busy thread queue $B2$.

Step 3 If $j < h$, add the value of j by 1 and perform step 2; If $j \geq h$, perform step 4.

Step 4 For each busy thread in the busy thread queue $B2$, perform step 5.

Step 5 Taking out the busy thread of the bound queue Q_j and executing the busy thread, the thread completes the parallel topological analysis calculation for the branch set corresponding to each element contained in the queue Q_j.

3. Simulation Analysis

The topology analysis of each local coal mine high-voltage power supply system included in Figure 1 is completed based on the parallel network topology analysis method. The simulation results are shown in Figure 2.

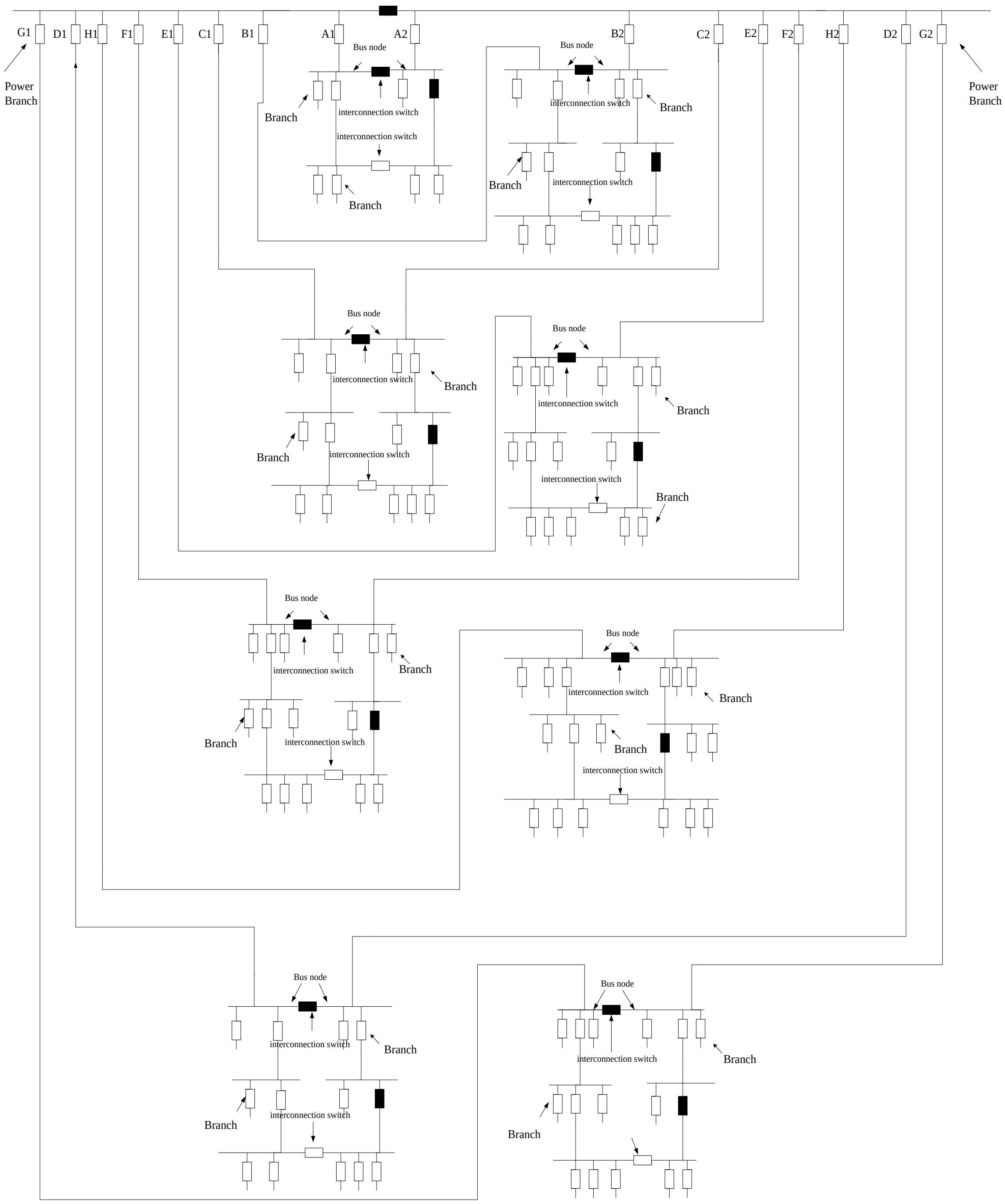

Figure 1. High voltage power supply system diagram of coal mine

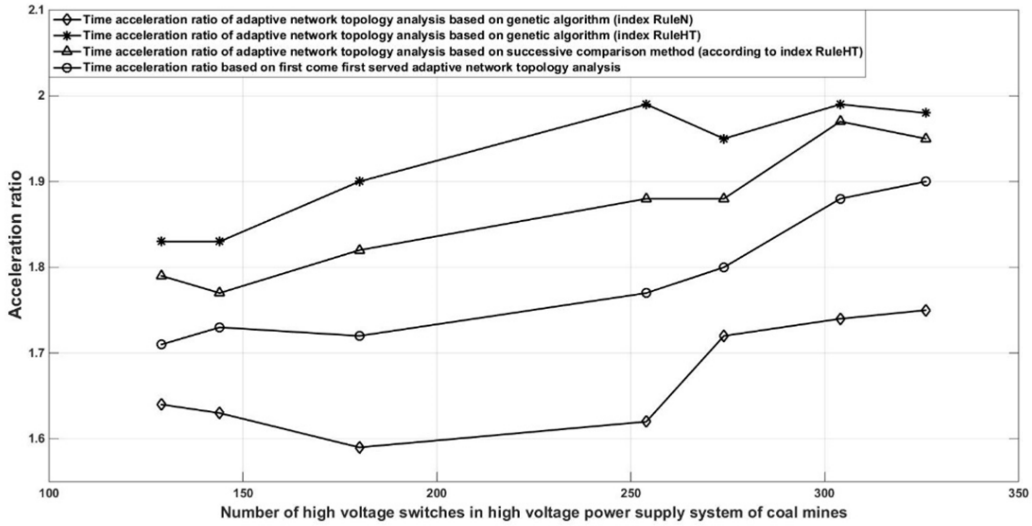

Figure 2. Self-adaptation network topology analysis time

Figure 2 shows the time speedup diagram of adaptive topology analysis based on first-come first-served, successive comparison, and genetic algorithm. From Figure 2, it can be seen that according to the index $RuleN$ (number of high voltage switches), the time overhead acceleration ratio of topology analysis based on genetic algorithm is lower in power supply systems of all sizes than that based on first-come first-served complete topology analysis. It can be seen that the parallel scheduling packet based on genetic algorithm (GA) based on index $RuleN$ does not improve the computational efficiency; on the contrary, it leads to a decrease in parallel computing efficiency. Therefore, in the parallel scheduling grouping based on genetic algorithm, indicator $RuleN$ is not applicable.

As shown in Figure 2, the time overhead acceleration ratio of topology analysis based on index $RuleHT$ (historical topology analysis time) and successive comparison method is higher than that based on first-come first-serve topology analysis in power supply systems of all sizes. Therefore, it is compared with the adaptive topology analysis algorithm based on first-come first-serve. Compared with the adaptive topology analysis algorithm based on index $RuleHT$ and successive comparison method, the efficiency of network topology analysis is effectively improved.

According to the index $RuleHT$ (historical topological analysis time), the time overhead speedup ratio of completing topology analysis based on genetic algorithm is greater in power supply systems of all sizes than that based on the successive comparison method. Compared with the adaptive topology analysis algorithm based on the successive comparison method, the adaptive topology analysis algorithm based on genetic algorithm based on index $RuleHT$ further improves the efficiency of network topology analysis. Therefore, compared with other parallel adaptive topology analysis algorithms, the parallel topology analysis algorithm based on genetic algorithm can improve the computational efficiency and reduce the time overhead.

By default, the high-voltage power supply system in coal mine is operated in different modes. When a short-circuit fault occurs in the high-voltage power supply systems of coal mines, the operation mode of the power supply system will change. The relay protection value needs to be calculated again, and the network topology analysis model needs to be rebuilt. However, for the self-adaptive parallel network topology analysis algorithm based on successive comparison method or genetic algorithm (according to index $RuleHT$) proposed in this paper, after the state of some interconnection switches have changed, the operation mode of high-voltage power supply systems in coal mines has changed. However, according to the principle of the above algorithm, when the operation mode changes, the parallel scheduling grouping based on genetic algorithm (according to the index $RuleHT$) will not change, so the original scheduling grouping results can be directly used for parallel topology analysis to effectively improve the computational efficiency. Therefore, when the operation mode changes, the parallel topology analysis algorithm based on genetic algorithm can effectively reduce the time overhead.

4. Conclusions

The existing topological analysis methods based on correlation matrix for coal mine high voltage grids have the problems of high time complexity and low computational efficiency. By introducing the first-come first-served parallel scheduling algorithm into the above topology analysis method, the computational efficiency can be improved to a certain extent. In this paper, an adaptive topology analysis algorithm based on a successive comparison method and genetic algorithm is proposed, and it can further improve the parallel dispatching efficiency of the topology analysis of coal mine high-voltage power networks. The simulation results show that the adaptive topology analysis algorithm based on genetic algorithm can improve the computational efficiency and reduce the time overhead better than other algorithms can.

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