The Method of Improving the Performance of Network Analysis Application for the Whole Power Grid

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Abstract. With the rapid development of UHV AC/DC hybrid power grid, it is required that the Network Analysis Application have the ability of unified analysis and high-performance computing. In this paper, the time-consuming analysis of each sub-function of Network Analysis Application is carried out to realize the performance bottleneck analysis of the whole process of network analysis. It is proposed that the performance of network analysis should be improved in three aspects: data input and output, topology analysis and core computing of Network Analysis Application. In the aspect of data input, the grid model data service is constructed to realize the combination of measurement reading and model reading, and the parallel model verification and boundary equivalence are completed; In the aspect of data output, it can be parallelized by table, block and equipment; In the aspect of topology analysis, the shared memory programming model OpenMP is adopted, and based on the fork/join parallel mode, its parallelization is realized; In the aspect of core computing, the existing parallel computing methods are summarized, and through the actual power grid simulation analysis, it puts forward the parallel computing mode applicable to different scale power grids and different applications. Finally, the effectiveness of this method is verified by comparing the optimized performance of state estimation.

1. Introduction
With the rapid development of UHV AC/DC hybrid power grid, the inter-regional and inter-provincial power grids are increasingly closely linked. The problems of AC-DC coupling, cross-regional resource optimization, global impact of local faults, large-scale interconnection of intermittent new energy generation and clean energy absorption require that the Network Analysis Application of Dispatching & Control Center at state, branches of state and provincial have the ability of unified analysis and high performance computing. Network-wide unified Network Analysis has the characteristics of diversified services, complex simulation models and huge computing scale. In addition to the algorithm, the current research mainly focuses on the use of CPU parallel acceleration or CPU + GPU parallel acceleration method to improve the performance of network analysis. However, through the bottleneck analysis of network analysis performance, the time-consuming ratio of data input, data output and topology analysis
is very high, and the performance of application function input and output and topology analysis needs
to be further improved.

On the one hand, this paper studies the performance improvement method of the data input and output
of application function and the topology analysis, so as to realize the improvement of network analysis
application computing performance. On the other hand, it summarizes and analyzes the parallel
computing method of core algorithm, and through the actual power grid simulation analysis, it puts
forward the parallel computing mode applicable to different scale power grids and different applications.

2. The current research status of Network Analysis Application performance

The Network Analysis Application is to analyze and evaluate the operation of power grid, analyze the
impact of fault on the safe operation of power grid, and provide accurate real-time data sections for other
on-line analysis applications. The Network Analysis Application mainly includes state estimation,
dispatcher power flow, sensitivity analysis, and static security analysis, short-circuit current calculation,
probability power flow and other functions. In recent years, the research on the Network Analysis
Application mainly focuses on improving the computational speed and accuracy.

In order to improve the computational speed of Network Analysis Application, there are three main
methods at present. One is to adopt the measures of boundary equivalence, model simplification or
algorithm simplification, which leads to the problem of losing the accuracy of network analysis and
calculation. The other is to improve the speed of Network Analysis Application based on multi-channel
and multi-core CPU parallel computing method [1-3], which generally adopts coarse-grained parallel
computing method of sub-task or network model partition. Limited by the parallelism of the method and
the parallel processing capability of CPU, there are bottlenecks in its acceleration performance for large-
scale power grid network analysis. Thirdly, based on the new high-performance computing software
and hardware technology, combined with the applicable algorithm and optimization application program,
The Network Analysis Application based on GPU acceleration is realized [4-6]. None of the methods
mentioned above involves the improvement of input-output and topology analysis performance. None
of the methods mentioned above involves the improvement of date input-output and topology analysis
performance.

3. Bottleneck analysis of the Network Analysis Application performance

Take the old version state estimation of the Smart Grid Dispatching and Control Systems (D5000 for
short) as an example to carry out performance analysis. The execution flows of power flow calculation,
static safety analysis, short-circuit current and sensitivity analysis functions are similar to that of state
estimation, and that will not be described here. The overall process and time-consuming analysis of state
estimation are shown in table 1. The data in the table is the average time-consuming of 5 traditional state
estimation computing in a day of state grid.

| steps               | Name of sub-function                          | time consuming(s) |
|---------------------|-----------------------------------------------|-------------------|
| data input          | read SCADA measurement                        | 2.435             |
|                     | read power grid model of real-time library for application | 3.255             |
|                     | model verification and boundary equivalence   | 17.712            |
| topology analysis   | topology analysis of the whole grid           | 7.559             |
| Core computing      | iterative computation                         | 74.717            |
| Data output         | organize and write back the calculation results to the real-time database | 5.052             |
|                     | Output status estimate QS file                | 2.904             |
|                     | statistical qualification rate and write back history database | 2.375             |
|                     | Other log files                               | 4.958             |
|                     | Total time                                    | 120.967           |
The functional processes of the Network Analysis Application generally include:

1. Data input: acquire the data of power grid model and measurement from the real-time database and history database of relevant applications;
2. Network topology analysis, includes bus topology analysis and network topology analysis;
3. Iterative calculation, generally includes generating node admittance matrix, Jacobian matrix, solving modified equation, iterative solution, power flow value and other analysis results.
4. Write back results, including a large number of real-time or historical database data write back.

It is found in Table 1 that the data input-output and topology analysis time consuming of traditional D5000 state estimation accounts for about 38.233% of the total time. Data throughput of other applications such as dispatcher power flow, static security analysis, short-circuit current, sensitivity analysis and so on is basically similar to that of state estimation, and other applications in the core calculation part are different. At present, CPU multi-core parallel and GPU parallel are introduced to solve the computing speed of each core calculation equation of network analysis, however, from the above analysis results of the application function performance, the data input-output performance of the application function also needs to be further improved.

4. Computing Performance improvement method of the Network Analysis Application
The computing performance of the Network Analysis Application is improved in three aspects: data input-output, topology analysis and core computing.

4.1. The performance improvement method of data input-output
Based on the existing D5000 system and various interfaces of the real-time data platform, this paper uses CPU to improve the performance of data reading and writing in parallel, so as to improve the performance of peripheral input and output.

4.1.1. Data input. By combining the measurement reading and model reading, the grid model data service is constructed, and the reading of SCADA measurement and grid model of application real-time database are realized, and the model verification and boundary equivalence are completed. The service implementation scheme is shown in Figure 1.

![Figure 1. Concurrent implementation of grid model data service.](image-url)
The service contains 5 sub functions.

Function 1: read the original application measurement by table in parallel

Function 2: read the target application grid model, and do parallel model verification. First, building regional and station relation model, station and equipment relation model by equipment, and then build the binary relation model of equipment and connection point by equipment, and carry out model equivalence according to equipment equivalence settings. Finally, the grid relationship model is generated by checking the parallel hierarchical relationship and connection relationship. Before receiving the new model release signal and new equivalent setting, the corresponding application model is resident in the memory and responds to the grid model data request of the target application in real time;

Function 3: parallel matching of original application measurement and target application model records by device keywords;

Function 4: send the measurement data of power grid model to the service bus according to the target application service request;

Function 5: the target application obtains the corresponding measurement data from the service bus, and can write back the real-time library or directly start the corresponding calculation according to the demand.

4.1.2. Data output. The parallel implementation scheme of data output is shown in Table 2.

| Function               | Sub-function                                                                 | Parallel implementation scheme                                      |
|------------------------|------------------------------------------------------------------------------|---------------------------------------------------------------------|
| Data output            | Organize and write back the calculation results to The real-time database     | Organize and write back corresponding tables in parallel by table. |
|                        | Output status estimate QS file                                              | It is divided into data blocks and output to string stream in parallel. Finally, the content of string stream is written to file. |
|                        | Qualified rate statistics and updating history database                     | The qualified rate of each item shall be calculated according to the equipment in parallel. |
|                        | Other log files                                                             | It is divided into data blocks and output to string stream in parallel. Finally, the content of string stream is written to files. |

4.2. Performance improvement of topology analysis

Using the shared memory programming model OpenMP, and based on the fork / join parallel mode, the parallel network topology analysis service of large power grid is implemented. The service is resident in the application server, and the overall process of the software is as follows:

1) When the service is started, the grid relation model is acquired by reading the real-time database of Smart Grid Dispatching & Control System. The power grid model is verified in parallel by stations and objects, and the index of model object array subscript relation is generated, and the power grid model is cut and divided according to the index;

2) Read the breaker/switch status, and the parallel station-bus analysis thread is derived from the main thread, which realizes parallel topology search for the sub network node-breaker/switch;

3) After the completion of all derived threads, the computing bus number shall be uniformly assigned;

4) The parallel system network analysis thread is derived from the main thread to do topology search for the computing bus and multi-terminal components in the sub grid, the electrical islands are generated in the sub grid, and determine the elecrtified state of the electrical island;

5) After all derived threads are finished, return to the main thread and start boundary coordination;
6) Receive the remote signal deflection information, and when the remote signal deflection is concentrated in a certain sub grid or the number is small, the local topology correction is done.

7) Send the electrified state of the equipment to the topology coloring program;

8) According to the computing request of on-line analysis application, the node-branch computing model is generated and sent to the corresponding application.

The parallel network topology analysis service program of large power grid blocks the data by the parallel network topology model, and adopts the unlocked computing mode to avoid the blocking time problem caused by data competition.

4.3. The parallel computing mode of Core computing

The core computing of network analysis application is mainly the iterative solution of sparse linear equation. After simulation analysis, considering the computing speed and stability, LU decomposition method is recommended. At present, the main method to improve the core computing speed is parallel computing. Its parallel computing mode mainly includes:

1) Single machine and multi-core CPU parallel computing mode, using the shared memory programming model OpenMP;

2) Single machine and heterogeneous parallel computing mode, using OpenMP + CUDA Programming Model;

3) Cluster and multi-core parallel computing mode, using the OpenMP + MPI (Message Passing interface) programming model;

4) Cluster and heterogeneous parallel computing mode, using OpenMP + CUDA + MPI programming model.

The selection of parallel computing mode in network analysis needs to evaluate the scale and timeliness of computing. Based on the simulation analysis of the existing models, it is suggested that single state estimation, single power flow calculation, single fault short-circuit current and other calculation should adopt single machine and multi-core CPU parallel calculation model to improve the efficiency of data interaction between processes. Under the abnormal operation mode of power grid, or when the computing node scale of power grid is greater than 10000 nodes, static security analysis and other batch calculation applications should adopt the full power flow and full fault scanning mode, and open the single machine and heterogeneous computing mode to improve the computing performance.

5. Performance comparison after optimization

Based on CPU parallelism and the I/O performance improvement scheme above-mentioned, the state estimation function is upgraded, and the computing performance is greatly improved compared with the traditional state estimation. Table 3 shows the performance analysis for the same grid section after the overall process optimization of state estimation.
Table 3. Performance comparison of the state estimation after the overall process optimization

| steps          | Name of traditional sub-function                  | Traditional state estimation time (s) | Name of optimized sub-function | State estimation time after optimization (s) |
|----------------|---------------------------------------------------|--------------------------------------|--------------------------------|---------------------------------------------|
| Data input     | read SCADA measurement                            | 2.435                                | the grid model data service    | 0.534                                       |
|                | read power grid model of real-time library for application | 3.255                                |                                 |                                             |
|                | model verification and boundary equivalence        | 17.712                               |                                 |                                             |
| Topology analysis | topology analysis of the whole grid              | 7.559                                | parallel network topology analysis | 0.09338                                  |
|                |                                                   |                                     | node-branch computing model    | 0.1587                                      |
| Core computing | iterative computation                             | 74.717                               | Parallel iteration by electrical Island | 1.8547                                    |
| Data output    | organize and write back the calculation results to the real-time database | 5.052                                | Result write back in Parallel | 1.3457                                      |
|                | Output status estimate QS file                    | 2.904                                |                                 |                                             |
|                | statistical qualification rate and write back history database | 2.375                                |                                 |                                             |
|                | Other log files                                   | 4.958                                |                                 |                                             |

6. Conclusion
By analyzing the computing time of each sub-function of Network Analysis Application, it is found that the time of data input-output and topology analysis time accounts for up to one third of the total time. At present, the research on the performance improvement of Network Analysis Application mainly focuses on the core computing methods. This paper proposes that the performance improvement of network analysis application should be carried out in three aspects: input and output, topology analysis and core computing. The parallel computing methods of data input-output and topology analysis are designed, and the basis for selecting the parallel computing mode of core computing is proposed. The methods described in this paper can greatly improve the computing performance of network analysis applications.

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