State Estimation Of Parallel Algorithms

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***Abstract*—Though the current power system state estimation is quite mature, with the interconnection of electric power system, the system linearization matrix increased, the size of serial method reveal certain disadvantages. On the execution efficiency is difficult to meet the requirements of computing speed, so the power system state estimation need to be faster, higher algorithm of numerical stability, guarantee the quality of power system. Real-time data due to the development of computer technology multicore CPUs has shown considerable advantages. This paper uses the method of minimum cut sets state estimation algorithm was improved on existing state estimation. In the actual test system for the trial, the large-scale system was used the minimum cut set apart for small systems, the Shared memory parallel programming model of OpenMp parallel technology (Open Multi - Processing), and this method is proposed.**

Keywords— power system state estimation; minimal cut sets ; OpenMp ; parallel algorithm.

I. INTRODUCTION

State estimation is real-time processing of data, it puts forward countermeasures to the problems of running, and provide the next operation decision-making. Thus it can guarantee the power system security and economy [1].It has a huge contribution on power system.

There are many ways to improve the computing speed. For example, sparse matrix technology energy, saving optimization code technology, partitioned matrix, triangular decomposition [2, 3]. These are based on the operations of a single processor, cannot satisfy the requirement of now later in the hierarchical state estimation [4]. It will calculate problem decomposition, using multiple processing machines make the solving of accelerated dramatically in local area, makes the calculation speed has a certain increase but because before undergoing secondary estimate requires data transfer between area, so the overall suppresses the computing speed grading type state estimation is the chief drawback of only one central processing unit, central processing unit to undertake all or most of the second operation, so it is easy to form the bottleneck problem, greatly influenced the stability of the numerical and real time.

In distributed parallel computing [5], now application is more, but different PC needs to solve the problem of coordination communication, to solve the problem of contact area boundary, the information interaction between the process by calling the function of communication, makes the program is relatively complex with increasingly larger grid scale, the factors to consider more and more, so high for this kind of high-dimensional sparse solution of the equation of large-scale power system needs to find new ways to adapt to the development of power grid. Multicore CPUs with the development of modern computer technology has shown considerable advantages [6], and developed the OpenMp compile environment, multi-core parallel technology, made possible by the parallel processing of large-scale power system calculation and estimate a reality.

This paper introduces the method of minimum cut sets in state estimation, using the segmentation method of a certain constraint condition to network matrix decomposition, tear into small to large system, tries to compile OpenMp environment, chunking each subsystem, makes the operation speed and improve the efficiency of CPU utilization, through the example analysis of the different nodes said the feasibility of this method.

II. THE MATHEMATICAL MODEL OF STATE ESTIMATION AND OPENMP

State estimation is also referred to as filtering, nature is extended on the measurement model and the data of a general trend, through real-time measurement system redundancy to improve data accuracy and automatic eliminate random disturbance caused by the wrong information, the operation of the estimated or forecast system[7].

A. The Mathematical Model Of State Estimation

In a given network connection branch under the condition of parameters and measurement system, nonlinear measurement equations can be written as in(1):

$$z = h(x) + v \tag{1}$$

Formula of the h (x) is a nonlinear equation of x , so can't directly find out the true value of x , so to the equations are linearized hypothesis, Taylor expansion(2) as in:

$$h(x) = h(x_0) + H(x_0)\Delta x \tag{2}$$

In the above formula ,there are(3)～(4):

$$\Delta x = x - x_0 \tag{3}$$

$$H(x_0) = \left.\frac{\partial h(x)}{\partial x}\right|_{x=x_0} \tag{4}$$

Here $H(x_0)$ is $m \times n$ order measurement vector jacobian matrix. State estimation is after the quantitative measurement z ,then x to make the objective function(5) attains a minimum:

$$J(x) = [z - h(x)]^T R^{-1} [z - h(x)] \tag{5}$$

Type R^{-1} is a diagonal matrix; the original equation (6) can be converted into, as in:

$$\begin{aligned} J(x) &= \Delta z^T \left[R^{-1} - R^{-1} H(x_0) \sum (x_0) H^T(x_0) R^{-1}\right] \Delta z \\ &+ \left[\Delta x - \sum (x_0) H^T(x_0) R^{-1} \Delta z\right]^T \sum{}^{-1}(x_0) \left[\Delta x - \sum (x_0) H^T\right] \times (x_0) R^{-1} \Delta z \end{aligned} \tag{6}$$

In the equation, there are:

$$\Delta z = z - h(x_0) \tag{7}$$

$$\sum (x_0) = \left[H^T(x_0) R^{-1} H(x_0)\right]^{-1} \tag{8}$$

On the type of the first item on the right and has nothing to do, to make the objective function $J(x)$ has a minimum, the second should be 0, there are:

$$\Delta x = \sum (x_0) H^T(x_0) \; R^{-1} \Delta z \tag{9}$$

$$x_1 = x_0 + \Delta x \tag{10}$$

$$x_1 = x_0 + \sum (x_0) H^T(x_0) \; R^{-1} \Delta z \tag{11}$$

So you get iteration as a result, obviously the result more than the initial value close to the true solution, a series of approximation value of x is obtained by this method gradually:

$$x = x^{(0)}, x^{(1)}, \ldots, x^{(l)}, \ldots, x_0$$

From the iterative sequence, it can choose a suitable x as to the true value for calculation. Criterion is to any of the following three equations(12）～(14):

$$(1) \left|\Delta x_i^l\right|_{max(i)} < \varepsilon_x \tag{12}$$

$$(2) \left|J(x)^l - J(x)^{l-1}\right| < \varepsilon_J \tag{13}$$

$$(3) \left\|\Delta \hat{x}^{(l)}\right\|_\infty < \varepsilon_a \tag{14}$$

In the type vector x in the serial number, weight l as the number of iterations, is selected according to the requirements of precision convergence criteria.

The basic state of weighted least squares estimation procedure block is shown in Fig. 1

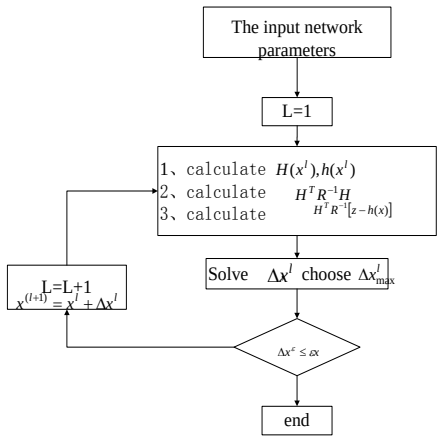

Figure 1. basic state of weighted least squares estimation procedure block

B. *OpenMp Compilation Environment*

OpenMp is based on multiple processors share the same memory devices, as shown in Fig. 2, the memory addressing is uniform continuous access when addressing space after completing write operation when the processor P0 completed, other processors P1, P2, …, Pn can access data in memory, and these processors are equivalent, with the same read and write access.

OpenMp execution mode of the Fork - Join form, when the main thread to need parallel execution task is to derive new thread Fork and work with the spawned thread, until the end of the parallel tasks, derived after the parallel threads suspend or quit, the program will be executed by the main thread to continue the Fork - the Join between the program area in parallel, the execution efficiency of parallel area is directly related to the process of execution speed.

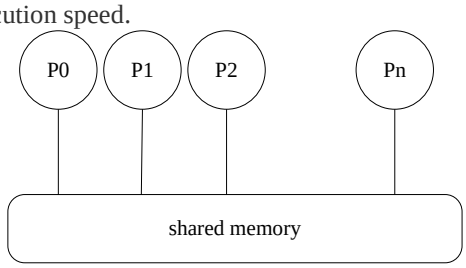

Figure 2. Shared memory multiprocessor architecture

Multi-core/CPU parallel computing and design tools, due to the use of the sharing memory way coordination between threads in parallel computing. It gives the multi-

core/CPU efficiency is very high in memory overhead small programming statements concise and straightforward, so programming easy and compiler implementation of some of the large complex problems, but also use other OpenMP parallel direct statement, OpenMP + Fortran programming problem can be refer to the document [8, 9].

III. STATE ESTIMATION BASED ON NETWORK OF MINIMUM CUT SETS

Traditional state estimation algorithm of weighted least-square method, has been quite mature, estimates are of good quality and relatively simple, is all kinds of algorithm based on least square method can be directly used in small power system, but with the expansion of power system network, the state estimation precision and speed requirements are constantly improve, the method in computational speed and accuracy of the traditional highlight certain defects in improving faster and better solution to this claim, to adapt to the development and requirements of modern electric power network

Combined with the requirements of power system network now and compile environment characteristics, the research emphasis on the minimum cut set of the graph theory, this paper has calculated the constraint of minimum cut set method , from any need of cut set of conditions, through the calculation of internal and external degrees of the vertices is poor, for minimum cut sets, the network is divided into different areas, repeated application of the proposed algorithm can cut the network into several sub diagrams, and each graph contains vertices to satisfy the constraint conditions of a given value for undirected connected graph is an effective algorithm of constrained minimum cut sets[10] the main steps are as follows:

Step 1 set the initial cut set Q undirected connected graph G (V, E) cut into two subgraph G1 (V1, E1) and G2 (V2, E2) and satisfy the given value, write adjacency matrix C column

Step 2 calculated outside, inside and inside and outside differential if the into calculation step 4)

Step 3 take corresponding vertex K value maximum and most numerical corresponding vertex M exchange, turn to step 2

Step 4 output constraint minimum cut sets of data

Adjacency matrix for the vertices in the above steps I and j direct links between the number of edges and is zero, the symbol for each step are(15）～(20)：

$$I_K(G1) = \sum_{j \in G1} C_{Kj} = \sum_{i \in G1} C_{iK} \tag{15}$$

$$I_M(G2) = \sum_{j \in G2} C_{Mj} = \sum_{i \in G2} C_{iM} \tag{16}$$

$$E_K(G1) = \sum_{j \in G2} C_{Kj} = \sum_{i \in G2} C_{iK} \tag{17}$$

$$E_M(G2) = \sum_{j \in G1} C_{Kj} = \sum_{i \in G1} C_{iK} \tag{18}$$

$$D_K(G1) = E_K(G1) - I_K(G1) \tag{19}$$

$$D_M(G2) = E_M(G2) - I_M(G2) \tag{20}$$

The network is divided into several regions, then use a simple and effective multi-core. OpenMP + Fortran programming method to design parallel program using fully.! $OMP SECTIONS /! OMP END SECTIONS parallel boot statements, realizing the load balance, to ensure that each thread in most of the time to keep busy. After the network is divided into different areas, each area of the algorithm is still the weighted least squares method for boundary node here requires boundary nodes in the adjacent area, each iteration of the voltage amplitude and phase Angle are equal, after the network partition algorithm flow chart shown in Fig. 2

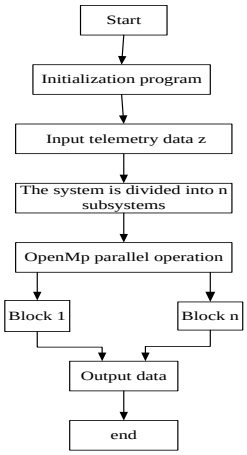

Figure 3. algorithm flow chart

It should be noted:

The regional internal using weighted least square method respectively to state estimation;

Each area according to related to this area of the rest of the measurement conditions of state estimation, and to solve the boundary node data;

The value from each region of the boundary node of the value of a weighted average of the estimates;

Maximize performance of the CPU, each CPU operations should be roughly equivalent.

IV. EXAMPLE ANALYSIS

In this paper, an example analysis program in Visual Studio 2008 Intel Visual Fortran11 compiler implementation, applied to Genuine Intel (R) CPU T2130@1.86GHz (2 cpus) PCS.

In the system under normal circumstances, respectively to four range scale equivalent network is a complete power system state estimation calculation, a modified parallel program performed by the double thread in this case, because we assume that the measured values of the weights of the same, because the area close

to measuring conditions, therefore, we can assume that the boundary nodes of all with the same measurement accuracy, in this way, the value of the boundary nodes on the estimate of the node to an area a mathematical average then serial execution time and parallel execution time comparison, analyze the speedup, verify the validity of the method.

TABLE I. DUAL-CORE COMPUTER PARALLEL COMPUTING ON COMPUTING TIME AND SPEED RATIO

Nodes	Branches	The serial execution time(s)	Parallel execution time(s)	Accelerate rate
24	**33**	**0.031**	**0.042**	**0.73**
30	**63**	**0.77**	**0.69**	**1.23**
118	**179**	**0.967**	**0.748**	**1.29**
238	**427**	**3.004**	**2.219**	**1.35**

Through the table can be seen that for a small example of parallel execution procedure is longer than the time needed for serial execution time, because for a small example, the efficiency of the system a small serial program itself is very high, the introduction of segmentation technology, combined with OpenMp parallel computing bring extra time consumption, this will affect the efficiency of parallel, lead to the comprehensive efficiency, the results did not meet expectations but as the scale parallel computing shows its advantages, but not according to the linear speedup. Because there are other aspects of the parallel influence each area is observable in addition, after serial and parallel comparison, can learn about the global estimate is still in the range of estimates, just slightly larger integral boundary point estimation error, but there are no data links between each area calculation, regardless of the data correlation, execution efficiency is influenced by various aspects, so that the program is easy to realize parallelization by OpenMp technology, speed up the calculation but there were plenty of synchronization points, OpenMp threads only after the synchronization points synchronization can continue to perform the back of the code, so it's very important to load balancing between threads.

V. CONCLUSION

This article through to four different scale of power system state estimation of equivalent network, analysis the effectiveness of the least square method based on OpenMp example calculation results show that after the parallel program execution have different increase, and with the increase of matrix of system scale and scale, the advantages of parallel processing after more apparent, better program speedup, CPU execution efficiency is high. In four or eight thread execution program execution may have greater speed improvement.

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