Network Partitioning of Large Power Systems Using Kernighan-Lin Algorithm

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***Abstract*— This work presents a simple and efficient method for large scale power systems network partitioning for distributed energy management system. Application of distributed computing in power systems involves two phases namely network decomposition and external network equivalencing. The partitioning is done in such a way that the number of nodes in each partition should he well balanced and the number of tie lines between them should be minimized. The decomposition is done without losing the observability of the network. In this paper Kernighan-Lin Algorithm is used for network partitioning and is proved to efficient on IEEE standard test system without losing the connectivity of the partitions.**

***Index Terms*— Network Partitioning, Distributed Computing, Kernighan-Lin Algorithm**

I. INTRODUCTION

POWER system simulation and analysis of very large scale networks has become increasingly important for efficient market operations and security of supply. Centralized control is not efficient enough to simulate very large transmission system within the required time and accuracy. Hence efficient computational algorithms like parallel and distributed computing becomes essential to overcome this problem. For distributed computing network partitioning becomes mandatory. In literature, graph partitioning is a fundamental problem studied extensively in theory and practice [1]. It is known to be NP-complete, but can be solved in polynomial time. Fast heuristics work well in practice. An important application of graph partitioning is load balancing for parallel computing, where each vertex corresponds to a computational task and the edges correspond to data dependencies. The balance constraint and minimum edge cut are the two major goals of graph partitioning techniques. The former balances the computational load and the storage requirement and the later minimizes the communication volume between the sub networks.

There are several graph partitioning methods like geometric techniques, combinatorial techniques, spectral methods and multilevel schemes [2]. The geometric techniques include Coordinate Nested Dissection (CND), Recursive Inertial Bisection (RIB) method, Space-Filling curve techniques and sphere cutting approach. Geometric techniques are solely based on coordinate information, if it exists or can be constructed. The goal is to group the vertices that are spatially near each other and it bisects the mesh recursively into smaller sub domains. The geometric techniques are very fast. There is no concept of edge cut or communication optimization in this method. Hence it may suffer from disconnected meshes in complex sub domains.

The CND is a geometric method which the bisection is based on the projections of the centers on the longest dimension recursively. This method is fast and easy to parallelize but the quality of partitioning is very low and may result in disconnected sub domains. The RIB tries to minimize the sub domain boundary. This method computes the principal inertial axis of the mass distribution and bisects orthogonal to the principle inertial axis recursively. This gives a faster and better quality partition than CND. The CND and RIB considers only single dimension at a time. Space filling curve techniques follow points of mass of mesh elements using locality preserving curves. This method is faster and better in quality than CND and RIB, but the disadvantage is that it works better only for specific type of problems. The sphere cutting method separates mesh by vertices in overlap graph.

The combinatorial methods include Levelized Nested Dissection (LND) method and Kernighan-Lin/Fiduccia-Mattheyses (KL/FM) method. The main disadvantage with the geometric techniques is that they group vertices that are spatially close using a coordinate system irrespective of their connectivity and hence combinatorial techniques score better. They use adjacency information of the graph to group the highly connected ones together. This method is reasonably fast with lesser edge cuts even though they are not easily parallelizable. The LND chooses a pseudo vertex and computes the distance to other vertices using the breadth-first search. When half of the vertices are assigned the graph is split into assigned and unassigned. This is repeated with different trials of pseudo vertex to minimize the edge-cut. The next method is the KL partitioning is based on refinement of an initial partition into two disjoint sets. This is done by swapping the vertices in between the partitions yielding the greatest reduction in the edge cuts. FM works by moving one vertex at a time by using a gain or loss value for each vertex

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along the partition avoiding local minimum.

The spectral methods are based on the adjacency matrix and handle the eigen value values for checking the connectivity. A discrete laplacian matrix is formed with the adjacency matrix and the diagonal matrix with the degree of the vertex as its elements. The largest eigen value is zero but the second largest eigen value measures the graph connectivity. The eigenvector corresponding to this value is the distance between the vertices. The sorted list is used recursively to create a k-way partition. This method give high quality sub domain splitting but computing the fielder vector is expensive. Finally the multilevel schemes consists of recursively applying graph coarsening, initial partition and partition refinement and Kernighan-Lin Algorithm falls under this category. The KL Algorithm is applied to travelling salesman problem [3] and in the design of VLSI circuits [4].

II. KERNIGHAN – LIN ALGORITHM

KL algorithm is a heuristic procedure for solving the graph partitioning problem [5]. It is most widely used in the area of digital and VLSI circuits design. The problem is defined as follows:

Let G (V, E) be a connected graph with V being the set of nodes and E being the set of edges. This heuristic procedure tries to partition the graph into disjoint subsets A and B of almost equal sizes, so that the sum of the weights of the edges T between the subsets is minimized.

For a node i,

I_i be the internal cost which is actually the sum of the cost of all edges between the node i and the others nodes in the subset A to which they are connected.

E_i be the external cost which is the sum of the cost of all edges between the node i and the others nodes in the subset B to which they are connected.

Create a random initial partition

REPEAT

Initialize partitions to a temporary set

Compute D for all nodes

FOR ALL Nodes in a set **DO**

Compute the maximum gain G

Interchange the nodes selected

Lock the interchanged nodes

Update D for all elements

END FOR

Find maximum gain G_{max} of all interchanges

IF $G_{max} > 0$

Exchange the nodes with max gain

ENDIF

UNTIL $G_{max} <= 0$

Completely connected partitioned graph

III. CASE STUDY

The power system has a hierarchical interconnected network in the order of generation, transmission and distribution. Many conventional and heuristic algorithms have been applied to this problem of network partitioning. The analysis was done in Intel Pentium IV, 3.40 GHz Processor with 1GB RAM using Matlab. Simulations of the proposed method of partitioning for distributed computing are carried out on IEEE 14 Bus, IEEE 30 Bus, IEEE 57 Bus System and IEEE 118 Bus System. Partitions of the IEEE standard system using the KL Algorithm are shown in Table 1. The nodes shown in brackets are the boundary buses. The schematic of the partitions made for IEEE 14 Bus system are shown in the Figure 1.

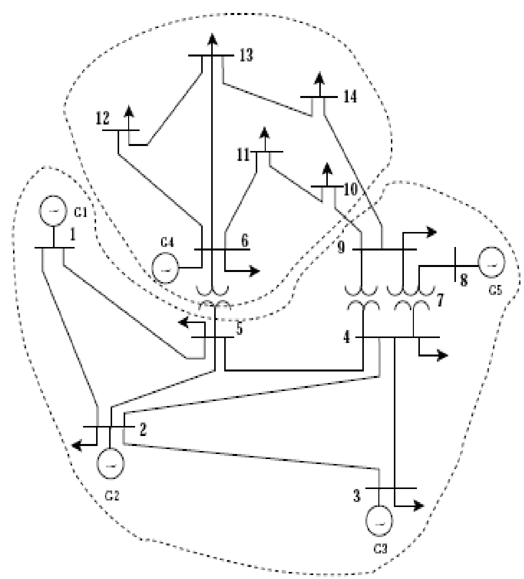

Fig. 1. Optimal Partition of IEEE 14 Bus System into 2 Clusters

TABLE I
PARTITIONING DETAILS OF IEEE TEST CASES

Test Case	Internal System	External System
IEEE 14 Bus	1 2 3 4 7 8 (5 9)	(6 10 14)11 12 13
IEEE 30 Bus	1 2 3 4 5 7 9 11 12 13 14 15 16 17 18 19 20 (6 10 21 23)	(8 22 24 28) 25 26 27 29 30
IEEE 57 Bus	1 2 3 4 5 6 7 8 9 12 16 17 18 19 20 21 23 24 26 27 28 29 52 53 54 55 (10 11 13 14 15 22 25)	(30 38 41 43 45 46 49 51) 31 32 33 34 35 36 37 39 40 42 44 47 48 50 56 57
IEEE 118 Bus	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 25 26 27	(68 69 70) 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94

	28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 48 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 66 67 72 73 113 114 115 117 (24 47 49 65 71)	95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 116 118

IV. CONCLUSION

In this paper the Kernighan-Lin algorithm is used partition large scale power systems. An important application of this partitioning is load balancing for parallel computing, where each vertex corresponds to a computational task and the edges correspond to data dependencies. The balance constraint and minimum edge cut are the two major goals of graph partitioning techniques. The former balances the computational load and the storage requirement and the later minimizes the communication volume between the sub networks. The proposed method has been tested on IEEE standard test cases. This strategy can be easily implemented in a decentralized environment for distributed computing applications of a large interconnected power system networks like load flow, optimal power flow and state estimation.

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