

RESEARCH AND ANALYSIS OF ALGORITHMS OF POWER SYSTEM ISLANDING

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The graphs bisectioning algorithms are investigated and their applicability to islanding of the power system. The Kernighan-Lin algorithm, spectral method and multilevel kernel k - means approach have been analyzed with respect to the computational complexity and their applicability.

Key words: graph bisectioning, power system islanding.

Introduction

Controlled islanding prevents the spread of the wave of failure in the energy network with providing the supply to parts of its customers. Distributed generator continues to supply power even when some of generator removed [1]. There are two types of islanding – controlled (intentional) and not controlled (natural, inadvertent). For controlled islanding generator himself, the emergency part is disconnected from the network and the distributed generator continues to supply power of the local network. In case of not controlled islanding generator is not disconnected from the supply of energy network after failure condition. Such kind of islanding is a dangerous phenomenon that accompanied the spread of the wave crash, unexpected "live wires", damage of equipment of consumer electricity and other adverse events. Overloading can result to grid instability, and which, in turn, to not control islanding, leading to catastrophic accidents. Controlled islanding is conducted to failure localization and saving efficiency maximum number of grid customers. Controlled islanding can improve recovery of the system, management of network load and generation power in it. In Rajamani et al. (1999) [13] reported that without this approach, India could for a long time stayed without electricity in 1999 year. Agematsu et al. (2001) [3] inform that not controlled islanding where not exercising control by balancing the active and reactive power in 1999 year, would leave for a long time Tokyo without light when the plane crashed into her line electricity. The only way out from this situation - controlled islanding. Methods of controlled islanding must act quickly and in time, should be considered the cost of their development and implementation, because if they significantly increasing with the sizes of the grid, than their applicability is too low.

Consider methods and algorithms of controlled islanding. Mathematical model of the power systems is a weighted graph $G(N, B)$, where nodes are represent the sources of energy supply, consumers and branching, and the branches - line of energy transmission. Weights of nodes characterize the power, voltage and other characteristics of energy sources, weights of branches - the parameters of transmission lines. A goal of controlled islanding is the severance of the consumer and of the source of accident with minimizing the number of lines of discontinuity. It means that the problem is formally reduced to partition the graph into two parts, one of which includes a source of an accident, and the other - the rest of the network by minimizing the number of the network gaps. From a mathematical point of view, this problem belongs to the class of combinatorial type problem NP, because have exponential, namely factorial computational complexity. For problems of large dimensions, methods for the exact solution, such as branches and borders, or exhaustive of all options, is not suitable because it requires very large computing costs. Therefore, most research in the field of graph partitioning, mostly devoted to finding effective heuristic algorithms. [2] Most of the proposed islanding methods offer partition of the power grid into two pieces, namely, bisection.

Analysis of algorithms

For controlled islanding of power system and graph partitioning proposed a number of methods and algorithms. [1 - 21]. In Peiravi and Ildarabadi (2009) [2] is given a comparison of computing's requirements for the two algorithms of bisectioning of power system - "spectral method" and "multilevel

kernel k-means approach". Best solution in controlled islanding can be obtained only when it is partitioned into two parts, since such an approach would lead to larger islands compared with multi-sectioning partition. Restoring a bisected power system is easier than partitioning into many pieces. Computational complexity of each approach identified for several major and one of Polish power systems. Karypis and Kumar (1999) [9] propose to solve the problem in three stages: coarsening, partition of the coarsest graph, and refinement. They also presented a faster modification of the Kernighan–Lin algorithm [11]. Multilevel kernel k-means approach used in such applications, as image segmentation, social and genetic analysis, network analysis of systems [2]. Kernighan and Lin (1970) [11] proposed heuristic iterative algorithm of bisectioning, starts from an initial fission half where in each iteration a subset of nodes are searching from every preliminary partitioning with less the number of branches in the intersection.

Cherng et al. (1999) developed a two-level bisectioning algorithm combining a hybrid clustering technique with an iterative partitioning process for integrated circuits. Later, Cherng et al. (2003) presented a multi-level bisectioning algorithm by integrating a clustering technique and an iterative improvement. The scope of this method is energy systems where the graph partition can be used for various purposes. The task is to separate tires from a system into two or more groups to meet the stated purpose. Minimal cutest technique is used by Wang and Vittal (2004) [17] based on the grouping information.

Wang *et al.* (2008) proposed an adaptive clustering algorithm based on power system network topology, initial power flow and given architecture to address power system transient stability studies. The sizes of the small definition with using a number of constrains. The fundamental principles of Laplacian spectrum of graphs were initially introduced by Mohar (1991), Hagen *et al.* (1992) and others. In bisectioning, the graphs, partitioned into two parts, using the second smallest eigenvalues of the Laplacian matrix. The corresponding computed eigenvector given based on the partition. A graph's adjacency matrix, are needed to form the Laplacian matrix. The Laplacian matrix of an undirected, un-weighted graph is symmetric with one row and one column for each node. If the eigenvalues of Laplacian matrix are sorted by increasing value, the eigenvector corresponding to the second smallest eigenvalue of the Laplacian matrix is called the Fiedler vector and may be used in heuristics for various graph manipulations including spectral graph partitioning. The second smallest eigenvalue of the Laplacian matrix is greater, than 0 if graph is connected. The Laplacian matrix forming as follow: The element for which $i = j$, the sum of the branches adjacent to the respective nodes, which it is presented. Other values are defined as meaning the opposite branch that goes from nodes i to nodes j . Then, determine eigenvalues and eigenvectors of a matrix. The second column (or row) of the matrix is called the Fiedler vector, it can be used to bisectioning of graph as shown in Fig. 2. The axis Y - a eigenvector, the axis X - nodes. Computational cost to determine the eigenvalues and Fiedler vector is a "bottleneck" of bisectioning algorithm as they have computational complexity $O(n^3)$. Definition Fiedler vector is the most costly operation in respect of computational time of partition.

To quickly obtain solution in many cases Fiedler vector is approximate. Multilevel versions of spectral method that use it at different levels are widely used. Holzrichter and Oliveira (1999) [8] proposed a spectral approach, which definition of vector Fiedler made with applying Davidson algorithm [8].

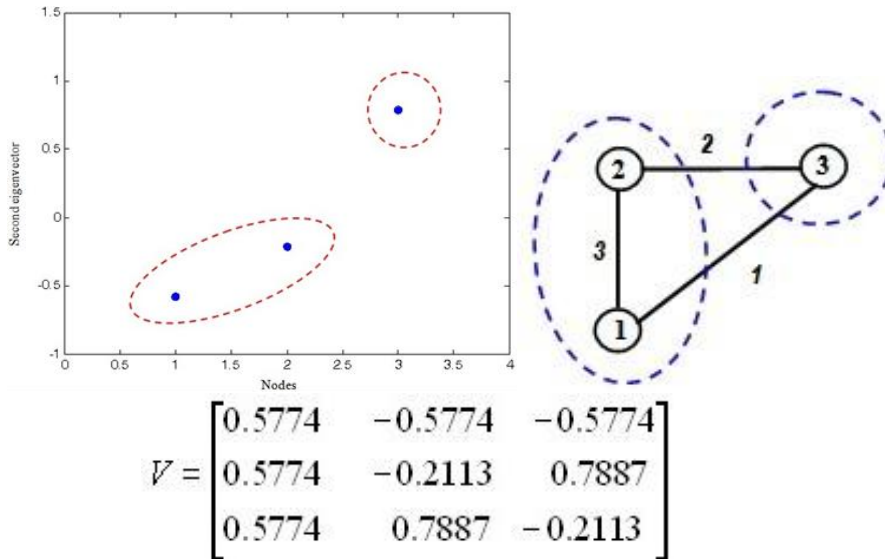


Fig 1: Graph partition with using Fiedler vector [2].

Although minimal generation/load imbalance is a very important factor in islanding other issues should also be considered. As proposed by Rehtanz (2003) spectral bisectioning of the power system may be performed as follows:

1. Compute the power flow of the power system network
2. Convert the power system network into a graph $G(N,B)$ with n nodes and b branches.
 - 2.1. Each bus of the power network is a node of the graph G .
 - 2.2. Each transmission line of the power system is a branch of G .
 - 2.3. Assign the weight of each branch of G as the absolute value of real power flow.
3. Compute the Laplacian matrix Q of Graph $G(N,B)$ as follows:
 - 3.1. Compute the adjacency matrix A and diagonal degree matrix D of graph $G(N,B)$.
 - 3.2. The Laplacian matrix $Q=D-A$
4. Compute the second smallest eigenvalue λ_2 of the Laplacian matrix Q .
5. Compute the real eigenvector associated with λ_2 call it x_2 ,
6. Map x_2 into a heuristic partition vector of the graph $G(N,B)$.
 - 6.1. Sort entries of x_2 to obtain the sorted vector v of node indices.
 - 6.2. Place all nodes in partition U .
 - 6.3. For $i=1$ to $n-1$

Move v_i from partition U to partition W . Calculate the cut set size of the (U, W) partition.

7. Find the optimal (U^*, W^*) partition that has the minimum cut set size among the above $n-1$ different partitions.

Spectral partitioning and kernel k-means approach are two seemingly different methods for graphs partition. However, they are very similar mathematically and this helps design a fast kernel-based multilevel graph partitioning algorithm that is better in terms of speed, memory storage and quality as shown by Dhillon et al. (2005)[6]. Peiravi and Ildarabadi (2009) [11] proposed to apply the multilevel kernel k-means approach to controlled islanding. Since in this approach there is no need to calculate the eigenvectors, it is much faster than the spectral method. The approach uses the method named Metis.

For controlled islanding it is also advisable to use the method of optimal folding scheme [19-23]. In this method, the first (1974) proposed to implement partitioning scheme for several stages: the selection of hierarchically nested clusters by coagulation scheme for the selected criteria, selection on a tree collapse the desired initial partition, the best approximation to the given constraints, and optimize it. Studies have shown that the method has a linear-logarithmic computational complexity, making it suitable for problems of large dimensions, possibility of various constraints, including the choice of any number of parts of the partition, the performance of multi-level partitioning, and provides high quality of the solutions.

Computational complexity of algorithms

Computational complexity of islanding algorithms, depend on their technique. This "bottleneck" approach determines the applicability of the algorithm because need rapid response in the event of an accident. For spectral approach this complexity is determined by the number of cost required to compute eigenvalues and eigenvectors of the matrix Laplace. For a dense matrix of Laplace, this complexity is $O(n^3)$. In real power systems, what descriptions by strong sparse graph, it is wouldn't need much more computational costs.

Computational requirements of the multilevel kernel k - means approach to bisectioning of power system, for each of iteration, is $O(n^2)$. In modern, large-scale power systems where there is excessive tenuity, for each iteration will only have $O(nz)$ operations where z means the number of nonzero entries in the matrix, which is proportional to the number of transmission lines in the power system. Since, in the approach of multilevel kernel k means to bisectioning of power system, we must compute the eigenvectors it strongly reduces the computational complexity of the problem, making it equal to that in fact, is much less well than is necessary for the best implementation of spectral approach.

Peiravi and Ildarabadi (2009)[2] presented a study of the spectral method and multilevel kernel k – means approach to deliberate islanding of three typical power systems, such as bus IEEE 118, IEEE 300 bus and 2746 bus Polish power systems. Much less computational time required multilevel kernel k – means approach, compared with the spectral method [fig.2].

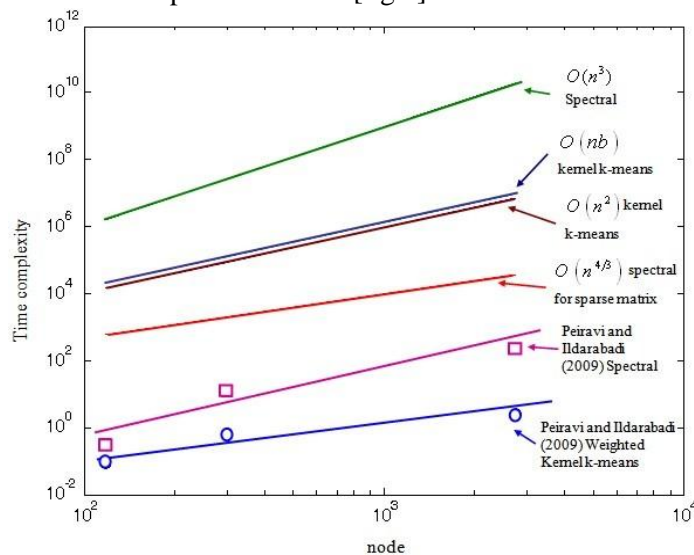


Fig. 2: A comparison of expected computational time [2].

Conclusions

All transactions of changing power system structure for its islanding in case of an accident must be performed in a very short time. It is believed that all the calculations for controlled islanding to be performed during less than 500 ms [2]. Many proposed methods are slow for a quick application to large power systems. Analyzing the existing techniques and algorithms of islanding, we can conclude that their "bottleneck" is a large computational complexity is not always sufficient quality and the ability to consider the desired limits. If the network itself does not have time for a while to locate the problem, then controlled islanding can improve its reliability. The bad situation is when unstable voltage with an imbalance between load and generation in network lead to costly consequences. The only way out of this situation - is controlled islanding. It is necessary to develop a fast, reliable and not too costly methods and software that would solve the problem islanding of power system during malfunction in the system, and other same applied problems. Desirable for this purpose is the application of optimal folding scheme [19-23].

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