http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 13 (18): 2749-2754, 2014
ISSN 1812-5638

ansinet
Asian Network for Scientific Information

RESEARCH ARTICLE OPEN ACCESS

DOI: 10.3923/itj.2014.2749.2754

A Constraint-Based Clustering Method for Automatic Voltage Control Soft Partitioning and Partition Result Evaluation

[1]Guo Ziming, [2]Liu Songnan and [3]Gong Zeping
[1]State Grid Jibei Electric Power Company Limited, Xicheng, Beijing, 100053, China
[2]Department of Electrical and Electronics Engineering, Dalian University of Technology, Dalian, 116024, China
[3]Beijing KeDong Electric Power Control System Co. Ltd., Haidian, Beijing, 100192, China

Corresponding Author:
Guo Ziming,
State Grid Jibei Electric Power Company Limited, Xicheng, Beijing, 100053, China

ABSTRACT

In order to better meet the requirements of automatic voltage control, this study proposes a constraint-based clustering method for power grid soft partitioning. By pre-setting boundary conditions into the clustering algorithm, this method solves the problems that exist in the traditional method, in which one needs to artificially determine the number of partitions and a whole partition contains isolated bus only. Next, the study proposes a method to further improve the partition result by regulating the few unreasonable buses. Then, this study proposes a partition result evaluating method based on electrical gravitation. This evaluating method provides a reliable basis for verifying whether the boundary conditions are reasonable and distinguishing the merits of different partitioning methods. At last, the partition result of this study method is compared with the existing method. The comparison results show that this study method can better meet the requirement of automatic voltage control.

Key words: Automatic voltage control, second voltage control, constraint-based clustering, partitioning, clustering result evaluation

INTRODUCTION

In past few years, Chinese power grids have been expanding in order to better satisfy the need of industry development. The establishment of global voltage and reactive power optimization system has become one of the key issues to ensure the safe and economic operation of grid. Automatic Voltage Control (AVC) plays an important role to improve the safety and economy of power system and affects both researchers and operators. In a variety of AVC solving scenarios, the hierarchical grid voltage control scheme proposed by the French EDF achieves some practical results in France (Paul *et al*., 1987), Italy (Arcidiacono *et al*., 1990), Belgium (Piret *et al*., 1992) and Spain (Sancha *et al*., 1996) to reach the target of the AVC, some domestic regional power grids apply three/two voltage control mode based on soft partitioning and achieve good control effects (Guo *et al*., 2005).

In the hierarchy voltage control strategy, grid is divided into several control partitions which are decoupled from each other. Each partition selects a reactive source control bus as the key bus and selects a load bus as the controllable pilot bus. The controllable pliot bus mentioned should be most voltage representative. To realize the purpose of controlling the voltage in the partition, the voltage changes of controllable pilot buses are monitored and the setting voltages of key buses are adjusted suitably. Furthermore, the reactive power output of the key buses can be controlling automatically (Guo *et al*., 2005; Lagonotte, 1991; Lagonotte *et al*., 1989; Sun and Zhang, 2002).

Undoubtedly, dividing a grid into decoupled partitions is the key to achieve hierarchical voltage control. In recent years, researchers has proposed quite a few methods such as partitioning method based on clustering analysis in Mvar control space (Guo *et al*., 2005), Jacobian matrix eigen structure variation mode of the load flow and network partition (Yang and Han, 2005) and partitioning method of multi-threshold decomposition de-coupling (Ding *et al.*, 2004). On the basis of defining equivalent electrical distance (Lagonotte, 1991; Lagonotte *et al.*, 1989), study (Guo *et al.*, 2005) first proposed the power network partitioning based on clustering analysis in Mvar control space which has realized the application in different grids (Guo *et al.*, 2005; Li *et al.*, 2008). In this method, the clustering process belongs to the traditional agglomerative hierarchical clustering method. However, this method is an unconstrained clustering method. For the grids of which the actual situation is different, the following problems may occur in the course of the actual partitioning: (1) With the decreasing number of partitions, there isn't an obvious plateau appearing in merge distance curve, so the number of the partitions can't be determined and (2) In the partition result, a whole partition contains isolated bus only.

On the basis of the existing partition methods, integrating the Mvar control space and the idea of constraint-based clustering, this study proposes a constraint-based clustering method of power grid soft partitioning for AVC. In this method, boundary conditions which meet the requirements of AVC are firstly pre-setting. Then the conditions are integrated into the clustering algorithm to modify the merger conditions, so the search process of clustering are limited. This method can effectively solve the problems that exist in the traditional method. Then the study proposes a method to further improve the partition result by regulating the few unreasonable buses.

At last, this study proposes a partition result evaluating method based on electrical gravitation. By integrating the electric distance in the Mvar control space and the concept of gravity, electrical gravitation between load buses can be obtained to compare the cohesion of each partition. This method provides a reliable basis for verifying whether the boundary conditions are reasonable and distinguishing the merits of different partition methods.

MATERIALS AND METHODS

Mvar control space: In studying the voltage control problems of transmission system, the weak coupling between active and reactive power can be ignored, hence following equation is obtained:

$$\Delta Q = L.\ \Delta V \tag{1}$$

In the normal operation mode, Matrix L is reversible, so:

$$\Delta V = S_{QV} \tag{2}$$

In Eq. 2, $S_{QV} = L^{-1}$ and it is a matrix about sensitivity relations between reactive power injection changes and the voltage changes and it reflects the tightness of connection between any two buses. On this basis, equivalent electrical distance between any two buses can be defined by Eq. 3 and 4.

$$\alpha_{ij} = \left|\frac{\Delta V_i}{\Delta Q_j}\right| \Big/ \left|\frac{\Delta V_j}{\Delta Q_j}\right| = \left|\frac{\Delta V_i}{\Delta V_j}\right| \approx |S_{ij}| / |S_{jj}| \tag{3}$$

$$d_{ij} = -\lg(\alpha_{ij}.\alpha_{ji}) \tag{4}$$

In Eq. 4, d_{ij} is the equivalent electrical distance between bus i and bus j and it reflects the tightness of connection between bus i and bus j in the reactive power and voltage levels and it is always greater than zero.

On the basis of equivalent electrical distance, study (Guo *et al.*, 2005) proposes the method of establishing the Mvar control space. Assuming that the number of the reactive source control buses in the system is g and the number of load buses is l, reactive source control buses constitute a collection Δ_{PV} and the load buses constitute a collection Δ_{PQ}. The reactive power control capabilities of each reactive source control bus can be as a one-dimensional space. In the Mvar control space, vector $(d_{i1}, d_{i2},..., d_{ig})$ can be as the coordinates of bus i and $i\varepsilon\Delta_{PQ}$. For any two load buses m and n, the electrical distance in the space between the two buses can be defined by Eq. 5:

$$D_{mn} = \sqrt{(d_{m1} - d_{n1})^2 + \ldots + (d_{mg} - d_{ng})^2} \tag{5}$$

Constraint-based clustering method: Unconstrained clustering method can't take the specific requirements of practical engineering application into consideration and to solve the problem, this study (Tung *et al.*, 2001) first proposed the idea of constraint-based clustering. By integrating the constraints into the clustering algorithm, modify the merger condition is modified and the search process of clustering is limited. The clustering algorithm can adapt to the specific requirements of practical engineering.

Partition method based on constraint-based clustering: To solve possible problems in the partition process, integrating with original method, this paper proposes the partition method based on constraint-based clustering.

Process steps of the method are:

Step 1: According to actual requirements, set the boundary conditions must be met by all partitions

Step 2: In the load buses collection Δ_{PQ}, the bus number is l. At first, each bus is as a partition Ω_i (I = 1, 2, 3..., l) and the number of partitions is Ngroup = l. The electrical distance D_{ij} in Eq. 5 is defined as the distance between partition Ω_i and Ω_j

Step 3: For each reactive source control bus i ($i\varepsilon\Delta_{PV}$), find the minimum electrical distance d_{ij} and the load bus j ($i\varepsilon\Delta_{PQ}$) and merge bus i into partition Ω_j

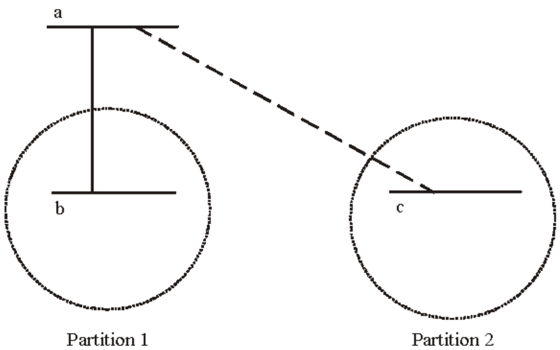

Fig. 1: Network structure of bus a

Step 4: Find every partition Ω_m which doesn't meet the boundary conditions ($m \leq$Ngroup). For partition Ω_m, find the minimum D_{mn} and the partition Ω_n($n \leq$Ngroup)

Step 5: For all the partitions that doesn't meet the boundary, find the minimum one among all the distances D_{mn} and find the corresponding partition Ω_m and Ω_n. Merge Ω_m and Ω_n as a new partition Ω_p and for every other partition Ω_q ($q \leq$Ngroup and $q \neq m$ and $q \neq n$), D_{pq} = min (D_{mp}, D_{mq}). Remove partition Ω_m and Ω_n and Ngroup = Ngroup-1

Step 6: Find whether there is any partition do not meet the boundary conditions, if there is, back to Step 4, if there isn't any one, the partition process is end

Regulate partition result: In the partition result obtained by the above method, there are still very few buses unreasonable, mainly because of the following two reasons:

- For a few load buses at the network edge (such as bus a), the network structure of it is shown in Fig. 1. In the network topology relationships, bus a is only connected directly with bus b of partition 1. But according to the definition of electrical distance (Eq. 5), in certain circumstances bus a might be nearest to bus c, therefore bus a is divided into partition 2
- For the load bus on the boundary of two partitions, the reactive source control bus with the most sensitive control ability to it might be in a different partition. This phenomenon has been discussed in Zhao *et al.* (2010)

In both above phenomena, it is obviously detrimental to the AVC of each partition, therefore, the partition result need to be regulated. Steps are as follows:

Step 1: Reserve reactive source control buses of the result in each partition and remove all the load buses. The new partitions Ω_i (I = 1,2,3..., Ngroup) are obtained

Step 2: For load bus i, among all the reactive source control buses, find the minimum d_{ij} and the bus j ($i \varepsilon \Delta_{PQ}$, $j \varepsilon \Delta_{PV}$)

Step 3: Find the partition Ω_m which bus j belongs to and partition bus i into this partition

Step 4: Repeat Step 2 and Step 3 till all the load buses are partitioned into the partitions

Partition result evaluating method based on electrical gravitation: The process of evaluating the partition result is actually the process of evaluating the clustering result. The partition result should meet the following two principles:

- After clustering, the differences between the buses of the same partition are as small as possible
- In the partition result, the buses of each partition are neither too many nor too few

For principle 1, integrating clustering result evaluating algorithm in a gravitational way proposed in Yu *et al.* (2007), this study proposed partition result evaluating method based on electrical gravitation.

In the Mvar control space, integrating the electric distance and the concept of gravity, electrical gravitation between load buses can be obtained. For any two load buses bus i and bus j, the electrical gravitation between them can be defined as:

$$F_{ij} = \frac{1}{D_{ij}}, (i \neq j)$$
$$F_{ij} = 0, (i = j) \tag{6}$$

For any partition such as partition Ω_m, assuming it contains buses $\{n_1, n_2, ... n_p\}$ and the number of buses is p, the cohesion F_{aggl} (Ω_m) of the partition is shown as Eq. 7:

$$F_{aggl}(\Omega_m) = \frac{2\sum_{i=1}^{p-1}\sum_{j=i+1}^{p} F_{n_i, n_j}}{p(p-1)} \tag{7}$$

The larger the F_{aggl} (Ω_m) of one partition is, the smaller the differences between the buses is and the better the effect of partition result is. Therefore the evaluating method provides a reliable basis for verifying whether the boundary conditions are reasonable and distinguishing the merits of different partitioning methods.

RESULTS AND DISCUSSION

Taking Liaoning power grid system for example, because there is no electromagnetic ring network in Liaoning power grid, the system can be divided into 500 and 220 kV system according to the principle of hierarchy and partition control in AVC. After the hierarchy, the 220 kV system is divided into 3 subsystems which are independent of each other which is shown in Fig. 2.

The three subsystems need to be further divided into partitions. Taking the subsystem 2 for example, in winter operation mode, there are 233 total buses. Among them, 39 buses are reactive source control buses and 194 buses are load buses.

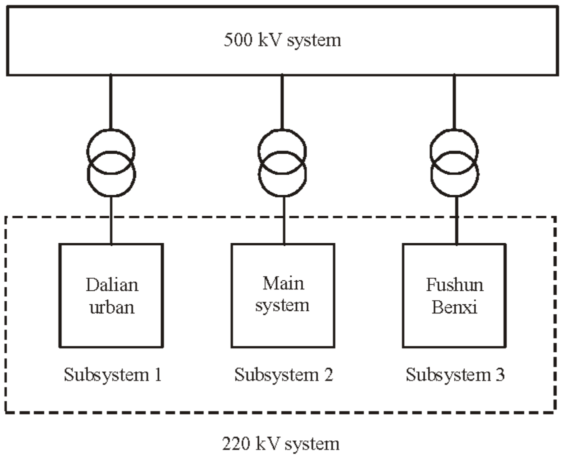

Fig. 2: Subsystem result of 220 kV system in Liaoning power grid

Table 1: Partition result when the number of partitions is 9 and 4

Partition No.	Administrative division	No. of buses in total	No. of reactive source control buses
1	Shenyang Tieling	46	10
2	Shenyang Liaoyang Chaoyang Jinzhou Fuxin Huludao Panjin	94	14
3	Dalian	25	3
4	Dandong	19	3
5	Yingkou Anshan	44	9
6	Zhangwu	1	0
7	Zhangdong Wind Farm Zhangbei Wind Farm	2	0
8	Wanjia Wind Farm	1	0
9	Taipingshao	1	0
1	Shenyang Liaoyang Chaoyang Jinzhou Fuxin Huludao Panjin	114	24
2	Dalian	25	3
3	Dandong	19	3
4	Yingkou Anshan	44	9

Table 2: Partition result in winter operation mode

Partition No.	Administrative division	No. of buses in total	No. of reactive source control buses
1	Shenyang Tieling	33	6
2	Shenyang	13	4
3	Shenyang Liaoyang	25	4
4	Panjin Fuxin	28	4
5	Chaoyang	16	2
6	Jinzhou Huludao	29	4
7	Dalian	26	3
8	Dandong	19	3
9	Anshan	23	5
10	Yingkou	21	4
11	Fushun	21	6
12	Benxi	20	2
13	Dalian Urban	21	5

Partition result of traditional method: In traditional method (Guo *et al*., 2005), the number of partition need to be determined firstly. With the decreasing number of partitions,there is an obvious plateau appearing in merge distance curve. The finally number of the partitions is just the number when the plateau appears.

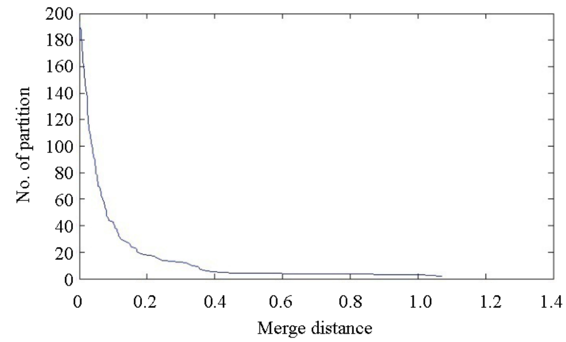

Fig. 3: Merge distance curve of 220 kV system in Liaoning power grid partitioning

But, in the process of partitioning Liaoning power grid 220 kV system, the following two problems occur:

- According to the partition method Guo *et al*. (2005), the merge distance curve with the decreasing number of partitions is shown in Fig. 3. As there is not any obvious plateau appearing, it is hard to determine a convincing number of partitions
- After artificially determining the number of partitions according to the merge distance curve (such as 9), the partition result of Liaoning power grid 220 kV system is shown in Table 1. No matter what the number of partitions is, there always partitions contain isolate bus only, such as Bus Taipingshao and Bus Zhangwu with the decreasing number of partitions, the number of isolated buses also decrease. When the number of the partitions decreases to 4, the isolated buses vanish and the partition result is shown in Table 1.

When the number of partitions is large, because a whole partition contains isolated bus only, AVC is impossible. When the number decreases to 4, some partitions contain too many buses. Taking partition 1 for example, the number of buses in the partition is 144 which is more than half number of the entire system's buses. In this case, AVC also doesn't work.

Partition result of present study method: After discussing with the grid operator according to actual requirements, the boundary conditions are set as:

- There must be at least one reactive source control bus in each partition
- The number of buses in each partition is no less than 10

In winter operation mode, the result of the partition method this study proposed is shown in Table 2 and Fig. 4.

Because of the geographical factors, the load of each prefecture-level city is relatively concentrated and the network topology connections between the buses in same prefecture-level city are tight which leads to the relatively near

Table 3: Comparison of the evaluating results of the two partition methods

This study partition method			Traditional partition method		
Administrative division	No. of buses in total	$F_{aggl}(\Omega_m)$	Administrative division	No. of buses in total	$F_{aggl}(\Omega_m)$
Shenyang Tieling	33	77.0004	Shenyang Hieling Liaoyang	144	29.8506
Shenyang	13	773.2657	Chaoyang Jinzhou Fuxin		
Liaoyang Shenyang	25	78.1849	Huludao Panjin		
Panjin Fuxin	28	169.0538	Dalian	25	476.0236
Chaoyang	16	342.5874	Dandong	20	85.4357
Jinzhou Huludao	29	146.2833	Anshan Yingkou	44	301.0890
Dalian	26	423.4859			
Dandong	19	97.65383			
Anshan	23	339.2988			
Yingkou	21	815.0358			

Fig. 4: Partition result of winter operation mode

electrical distance between these buses. Therefore the partition result is similar to the administrative divisions. But still two exceptions exist:

- In partition 2, partition 12 and partition 13, buses are from two different prefecture-level city, such as Shenyang and Tieling in partition 2. This is also because the geographical factors and network topology connections. The relatively near electrical distances between these buses making them in the same partition
- Also because of the geographical factors and network topology connections, few special buses are in the partitions which are different from administrative divisions, such as Bus Xiangpingbian in partition 4 and Bus Zhanwu in partition 7

Evaluating result of partition: According the partition result evaluating method based on electrical gravitation, by evaluating the two partition results of traditional partition method and this study method respectively, the cohesion Faggl (Ω_m) of the two results are obtained. The comparison of the evaluating results of the two partition methods is shown in Table 3.

According to the comparison results in Table 3, in the partition result of this study method, the bus number of every partition is neither too many nor too few and the cohesion of all each partition is relatively larger. So, it can be concluded that the pre-setted boundary conditions is logical and rational and the partition result of this study method can better meet the requirement of AVC.

CONCLUSION

This study proposes a constraint-based clustering method of power grid soft partitioning for AVC. This method solves the problems that one needs to artificially determine the number of partitions and a whole partition contains isolated bus only. Then the study proposes a method to further improve the partition result by regulating the few unreasonable buses. At last, this study proposes a partition result evaluating method based on electrical gravitation. This evaluating method provides a reliable basis for verifying whether the boundary conditions are reasonable and distinguishing the merits of different partitioning methods.

In the application in Liaoning power grid 220 kV system, the partition result of this study method is compared with the existing method. According to the comparison results, this present study method can better meet the requirement of AVC. Therefore, the method is the foundation for realizing the automatic voltage control.

REFERENCES

Arcidiacono, V., S. Corsi, A. Natale, C. Raffaelli and V. Menditto, 1990. New developments in the application of ENEL transmission system voltage and reactive power automatic control. Technical Report, Proceedings Paper CIGRE Session, Paper No. 38/39-06, pp: 1-7.

Ding, X.Q., W. Huang, W. Zhang, Y. Deng, Y. Ding, C. Fang and K. Li, 2004. A pilot bus voltage correction method based on voltage control area. Power Syst. Technol., 28: 44-48.

Guo, Q.L., H.B. Sun, B.M. Zhang and W.C. Wu, 2005. Power network partitioning based on clustering analysis in MVAR control space. Autom. Electr. Power Syst., 29: 36-40.

Lagonotte, P., J.C. Sabonnadiere, J.Y. Leost and J.P. Paul, 1989. Structural analysis of the electrical system: Application to secondary voltage control in France. IEEE Trans. Power Syst., 4: 479-486.

Lagonotte, P., 1991. Probabilistic approach of voltage control based on structural aspect of power systems. Proceedings of the 3rd International Conference on Probabilistic Methods Applied to Electric Power Systems, July 3-5, 1991, London, pp: 208-213.

Li, Z., Y. Liu, R. Liu and X. Niu, 2008. Network partition for distributed reactive power optimization in power system. Proceedings of the IEEE International Conference on Networking, Sensing and Control, April 6-8, 2008, Sanya, China, pp: 385-388.

Paul, J.P., J.Y. Leost and J.M. Tesseron, 1987. Survey of the secondary voltage control in France: Present realization and investigations. IEEE Trans. Power Syst., 2: 505-511.

Piret, J.P., J.P. Antoine, M. Stubbe, N. Janssens and J.M. Delince, 1992. The study of a centralized voltage control method applicable to the Belgian system. Proceedings of the International Conference On Large High Voltage Electric Systems, Volume 2, August 30-September 5, 1992, Paris, pp: 39-201.

Sancha, J.L., J.L. Fernandez, A. Cortes and J.T. Abarca, 1996. Secondary voltage control: Analysis, solutions and simulation results for the Spanish transmission system. IEEE Tran. Power Syst., 111: 630-638.

Sun, H.B. and B.M. Zhang, 2002. A systematic analytical method for quasi-steady-state sensitivity. Elect. Power Syst. Res., 63: 141-147.

Tung, A.K.H., J. Han, L.V.S. Lakshmanan and R.T. Ng, 2001. Constraint-based clustering in large databases. Proceedings of the 8th International Conference on Database Theory, January 4-6, 2001, London, UK., pp: 405-419.

Yang, P.P. and X.S. Han, 2005. Jacobian matrix eigenstructure variation mode of the load flow and network partition in the secondary voltage control. Relay, 33: 1-5.

Yu, Y.Q., X.G. Zhao, H.Y. Chen and G.R. Wang, 2007. Clustering result evaluating algorithm in a gravitational way. J. Northeastern Univ., 28: 1109-1112.

Zhao, J., F. Liu, Y. Deng, K. Li, Z. Fang and W. Huang, 2010. Network partitioning for reactive power/voltage control based on a mapping division algorithm. Autom. Electr. Power Syst., 34: 36-39, 56.