

# An Improved Partition Method of Reactive Voltage Control considering Dynamic Reactive Power Sources

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**Abstract**—Based on the partition idea of reactive power source priority followed by the load, an improved partition method is presented in this paper which makes the core of dynamic reactive power source and combined with comprehensive reactive regions/nodes sensitivity. Firstly, the electrical distance between the reactive power sources is defined based on the classic reactive/voltage sensitivity. The hierarchical clustering algorithm is adapted to form the cohesion of reactive power source partition. Secondly, a comprehensive sensitivity is formulated to describe the relationship of the reactive power source partition and a single load node. The electrical distance can be obtained by the logarithmic conversion of comprehensive sensitivity. Load nodes can be partitioned using the mapping partition method based on the electrical distance. This partition method can ensure that reactive power source whose electrical distance are close are partitioned in the same sub-region. Meanwhile the comprehensive control of the load node voltage can be guaranteed. Finally, The simulation results with IEEE39 node system demonstrate the effectiveness of the proposed method.

**Keywords**—comprehensive sensitivity; reactive/voltage control partition; electrical distance matrix; mapping partitioning methods; flow calculation analysis

## I. INTRODUCTION

The proper adjustments of reactive power and voltage should be made to ensure power system operating in the conditions of security and economy[1][2][3][4]. In order to control the reactive power/voltage quickly, an efficient strategy is partitioning the large complex power networks into several small-scale sub-regions which have many reactive sources. Due to the presence of different electrical coupling between the nodes of the electricity network, partitioning the large complex power network needs the

accurate understanding of the physical processes during the power system operation. Thus the partition results will strengthen internal electrical contact between nodes within a sub-region, meanwhile reduce the degree of electrical coupling between the sub-regions.

In the existing reactive voltage partitioning methods, the most mature partitioning algorithm is based on the electrical distance[4-10]. Using the Jacobian matrix of Newton's method[1] and B" matrix of PQ decomposition method [6] are two typical electrical distance calculation methods. The partitioning methods based on electrical distance are: cohesion hierarchical clustering algorithm [6], fuzzy clustering algorithm [7] and mapped zoning laws [8], etc. About the partition order on the power supply node and load node, the main consideration is: first power node partition then load node mapping partition scheme [8] and the first load then reactive power source node [9].

In this paper, a reactive sensitivity relationship matrix between reactive power sources is established, and thus reactive power source can be partitioned to ensure that each sub-region has the appropriate reactive power source. The sensitivity relationship matrix is calculated which describes the overall reactive power sources within a sub-region between the load node. The load nodes can be partitioned the proper sub-region on the basis of the reactive sensitivity relationship matrix. The simulation results with IEEE39 node system demonstrate the effectiveness of this partition method.

## II. SENSITIVITY MATRIX FOR REACTIVE POWER SOURCE PARTITION

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Reactive power source is crucial for the reactive power balance in the sub-region. In order to ensure adequate and reasonable partition of Reactive power sources, the electrical distance should be calculated between the power source node. A sensitivity matrix is formulated with the reactive power injection of source node between the voltage of other reactive power nodes.

For the study grid, using reactive correction equation of PQ decomposition method [10] can be expressed as

$$\begin{bmatrix} \Delta Q_G \\ \Delta Q_L \end{bmatrix} = \begin{bmatrix} B_{GG} & B_{GL} \\ B_{LG} & B_{LL} \end{bmatrix} \begin{bmatrix} \Delta V_G \\ \Delta V_L \end{bmatrix} \quad (1)$$

In the formula,  $\Delta Q_G$ 、 $\Delta Q_L$  are the injection increment of reactive source and load node;  $\Delta V_G$ 、 $\Delta V_L$  are the node voltage increments of power source and the load;  $B_{GG}$ 、 $B_{GL}$ 、 $B_{LG}$  and  $B_{LL}$  is the coefficient matrix.

To determine the sensitivity of the relationship between reactive power sources can make  $\Delta Q_L = 0$ , the equation can be simplified as

$$\Delta Q_G = [B_{GG} - B_{GL} B_{LL}^{-1} B_{LG}] \Delta V_G = S_{GG} \Delta V_G \quad (2)$$

In the formula, the coefficient matrix  $S_{GG}$  is the sensitivity matrix between reactive power injection and voltage, it is a symmetric matrix. According to this sensitivity matrix, reactive power source can be partitioned.

### III. COMPREHENSIVE SENSITIVITY BETWEEN REACTIVE POWER PARTITION AND LOAD NODE

#### A. Comprehensive Sensitivity Calculation Method

Suppose the number of reactive power sources is ng, the number of load node is L, the number of reactive power source partitions is m,  $j^{\text{th}}$  reactive power source partition denoted as set  $G_j$ , this partition contains  $n_{Gj}$  reactive power source. The comprehensive sensitivity between  $G_j$  and load node l is calculated as follows.

- Node type setting. For the reactive source node belonging to the set  $G_j$ , it is set to PV node if it participates in primary voltage control, otherwise it is set to PQ node. While those reactive source nodes in other partitions are set to PQ nodes [6].
- Make perturbation of load of each load node, including its active load and reactive load. The contact nodes in the network are also disposed as load node. After the comprehensive sensitivity computation, every node type is restored to the its original node type.
- The comprehensive sensitivity is calculated as follows.

$$S_i^{G_j} = \frac{\sum_{k \in G_j} \Delta Q_k}{\Delta Q_i} \quad (3)$$

- For all reactive power source partitions, the comprehensive sensitivity can be calculated by the above steps.
- According to the comprehensive sensitivity, a comprehensive sensitivity matrix between the reactive power source partition and load node is established[8] as follows.

$$S_{zone} = \begin{bmatrix} S_1^{G_1} & S_1^{G_2} & \Lambda & S_1^{G_m} \\ S_2^{G_1} & S_2^{G_2} & \Lambda & S_2^{G_m} \\ \Lambda & \Lambda & \Lambda & \Lambda \\ S_L^{G_1} & S_L^{G_2} & \Lambda & S_L^{G_m} \end{bmatrix} \quad (4)$$

#### B. Analysis of the comprehensive sensitivity

This method establishes sensitivity relationship matrix between nodes from the perspective of the normal operation of the power system. Comprehensive sensitivity in Formulation (3) reflects the comprehensive reactive response characteristic of the reactive power source partition with load nodes at the normal operating conditions. Generally, the sensitivity value is positive. the greater its value, indicating that the accused in the case of the same perturbation, the partition  $G_j$  reactive response output is greater than the other partition, it is clear that the node i should be partitioned into this sub-region. Therefore, the definition of a comprehensive sensitivity shows the comprehensive control effect power in the cluster for a controlled load nodes. The analysis results are apparently close to the actual power system operation.

This method differs from the algorithm proposed by [10], the key lies in the electrical distance between sub-region and load nodes. Reference [10] adapted the short-circuit impedance ideas as the electrical distance, but these calculation results were not representative of normal operating conditions between nodes. So it will have a great variation for the partition results finally.

### IV. MAPPING PARTITION OF LOAD NODE

On the basis of comprehensive sensitivity matrix in formula (4), the electrical distance [8] [10] between two node i and j is shown as follows.

$$d_{ij} = -\lg |S_{ij}| \quad (5)$$

Thus the electrical distance matrix D can be formed between the reactive power source partition and load node on the basis of formula (5). The matrix D is  $L \times m$ , L is the load of nodes, m is the number of partitions of reactive power source. Each reactive power source partition of the electrical load from the node constitute a row of a matrix D, so that we can get the electrical distance matrix D:

$$D = \begin{bmatrix} d_{11} & d_{12} & \Lambda & d_{1m} \\ d_{21} & d_{22} & \Lambda & d_{2m} \\ \Lambda & \Lambda & \Lambda & \Lambda \\ d_{L1} & d_{L2} & \Lambda & d_{Lm} \end{bmatrix} \quad (6)$$

The mapping partitioning algorithm in [8] adapted "minimum electrical distance" principle to partition the load node into the nearest reactive source partition. In this paper, the electrical distance formula (6) is calculated, the same principle of map partitioning algorithm is used which can reflect the comprehensive control of all reactive source node to load node.

This mapping partitioning algorithm can avoid the drawbacks of the cohesion charged node using the partition strike hierarchical clustering algorithm. In addition, the mapping partitioning algorithm ensures that the load nodes can be partitioned into the reasonable partition with the nearest electrical distance from the power sources the nodes.

## V. CASE STUDY

The standard IEEE39 node system is carried out to verify the feasibility and correctness of the proposed method. The partitions of 10 reactive source nodes (node 30-39) is shown in Table 1. In order to partition the load nodes into the partitions, the sensitivity matrix is shown in and Table 1. The partition of reactive power sources is shown in table 2. The results determine the partition of the system, specifically as shown in Fig.1.

From Table 1, reactive power source partition results are same as the results by [6] [8] [10]. The reactive power sources partitioning results which are based on the electrical distance calculation do not vary with the power flow. Those reactive power source with short electrical distance are partitioned into the same area. These results are stable and suitable for the voltage/reactive power management in the power systems.

In Fig.1, three load nodes 17, 26 and 27 are different with the partitioning results by [6] [8] [10]. The load node 26 and 27 were partitioned into the reactive power partition 38 in [8]. In this paper, these two nodes are partitioned into the reactive source partition 30 and 37. The main reason for this difference is considered in this paper the comprehensive control of many reactive power in the same partition, while the literature [8] only consider the control role of a single reactive power. In the literature [6] [8], the load node 17 is partitioned into the reactive power sources 30 and 37. According to the comprehensive sensitivity matrix of this paper, it is more reasonable that node 17 belongs to the 35 and 36.

TABLE I. ELECTRIC DISTANCE MATRIX

Load node	Partition					
	1	2	3	4	5	6
1	3.2841	2.2632	4.0871	5.6058	5.4228	5.5939
2	2.3425	3.8581	3.6690	4.7223	4.5384	4.6345
3	2.7643	3.9278	3.0212	3.9262	3.7423	4.4111
4	3.3818	3.7169	2.3906	4.0021	3.8182	4.8546
5	3.8500	3.5086	2.2100	4.3706	4.1867	5.2872
6	3.9575	3.5741	2.1730	4.4473	4.2634	5.3821
7	3.9358	3.2594	2.2028	4.4381	4.2542	5.3688

8	3.9403	3.1432	2.2334	4.4489	4.2650	5.3773
9	4.7967	2.2010	3.0082	5.3199	5.1360	6.3062
10	4.0821	4.0041	2.1472	4.3980	4.2141	5.4261
11	4.0311	3.8373	2.1545	4.4035	4.2196	5.4023
12	3.9469	3.8693	2.1465	4.2627	4.0788	5.2915
13	3.9360	3.9767	2.2059	4.2031	4.0192	5.2568
14	3.6555	3.9418	2.3813	3.8436	3.6596	4.9377
15	3.6579	4.3761	3.0242	3.2081	2.9017	4.5744
16	3.7064	4.7007	3.3017	3.0653	2.8814	4.4937
17	3.2327	4.4339	3.2677	3.3371	3.1532	3.9393
18	3.0206	4.2027	3.1604	3.5145	3.3306	4.1005
19	4.8697	5.8942	4.0296	2.1785	4.0229	5.6009
20	5.5505	6.6201	4.2999	2.0169	4.6731	6.2060
21	4.0935	5.0943	3.5767	3.4476	2.4199	4.8684
22	4.8591	5.8830	4.0256	4.1966	2.1608	5.5913
23	4.8105	5.8324	4.0006	4.1494	2.1620	5.5453
24	3.8074	4.8032	3.3765	3.1653	2.7299	4.5920
25	2.2800	4.3441	3.8588	4.8178	4.6339	4.1376
26	2.8131	4.6739	3.6988	4.0927	3.9088	2.9028
27	3.0205	4.5306	3.4601	3.6535	3.4696	3.2297
28	3.6524	5.5290	4.1048	4.8239	4.6399	2.2485
29	4.1250	6.1527	4.2969	5.2872	5.1032	2.1374

According to equation (1), (2) the sensitivity of the relationship between the reactive source matrix[10], whereby the reactive power source can be divided into six partitions, as shown in Table 2.

Partition no.	Reactive power sources node
1	30, 37
2	39
3	31, 32
4	33, 34
5	35, 36
6	38

Figure 1. Reactive Power Source Partition Result

From Fig .1, this power system has comparatively coupling between the reactive power sources partitions. With the increasingly close links between the grid, the boundaries between regions has gradually blurred. Meanwhile, the results from different methods of looking after the division of the region, and not a fixed, the only answer. Therefore, the regional division should belong to the category of fuzzy classification. Clustering point is the basic method of fuzzy mathematics in the merger issue, can effectively solve the problem of fuzzy boundary classification

From the partitioning results, the load nodes belong to the reactive power partition which are adjacent in short electrical distance. There are no typically irrational partitioning nodes into the reactive power regions which are large electrical distance. The simulation case shown in this paper can really describe the electrical distance electrical contact between the reactive power nodes and load nodes.

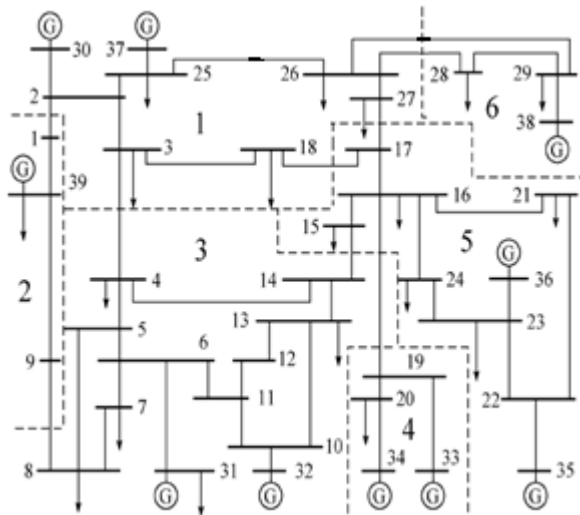


Figure 2. Partitioning results of IEEE39 node system

This algorithm is to form the nodes as a control partition. These partitions be used to achieve reactive power and voltage optimization analysis and calculation in the whole network. Partition control can significantly support the voltage and reactive power control effect and improve the reasonable distribution of voltage and reactive power. The proposed partition method provides a effective analysis tool for the safe and economic operation of power systems.

## VI. CONCLUSIONS

A tertiary voltage control mode is widely used in some modern power system. In this control mode, the electric power network is divided into several partitions. There are minor electrical coupling directly between these partitions. In each partition, one or more nodes which represents the voltage level are selected as the control unit. Generally, these control nodes are the dynamic reactive power sources in the power system.

Two sensitivity matrices are calculated, one is between reactive sources, the other is between the reactive power source and the load nodes. The mapping partition algorithm is adapted with the electrical distance. Voltage and reactive power control partitioning method in this paper has the following characteristics:

- The partition method can ensure the load node partitioned into the proper reactive source partition. There are reasonable reactive source in every partition, thus the reactive/voltage control effect can be easily implemented.
- The partition result of reactive power sources are stable, for the corresponding sensitivity matrix is less relevant to operation state of the power system.
- The comprehensive sensitivity reflect the clustered control role of many reactive power sources in the same partition. These comprehensive effect is consistent with normal operating conditions.

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