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A Line Loss Calculation Method for Arbitrary Partition of Power Grid Based on Measurement Resource and Matpower

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Abstract. The existing four-division management method for line loss in smart grids has problems such as the inability to verify line loss contemporaneity and low application flexibility. Considering that the rich data resources provided by data acquisition devices such as measurement meters in the smart grid are not fully utilized, an arbitrary partitioning line loss calculation method that fully utilizes measurement data resources is proposed. The method classifies the grid nodes according to the type of measurement data, obtains complete line power data, and then formulates the boundary equivalence principle of grid partition to realize arbitrary region partition of the power network. On the basis of network partition, the power loss of each subnetwork is calculated by using the power flow of matpower, which greatly increases the flexibility of smart grids line loss management. Taking a power grid in a certain area of Gansu as a case study, the effectiveness of the calculation method is verified.

1. Introduction

The Line loss rate is an important economic indicator for power supply companies [1]. At present, the line loss statistical assessment in china mainly adopts the four-division method. The four-division method refers to the four-division line loss management methods used by the power grid within the jurisdiction of the power supply enterprise, that is, the line loss management according to the voltage level, the power supply area, the power supply line and the substation [2,3]. When the grid size is small, the four-division method can accurately calculate the line loss. However, with the expansion of the grid size, the traditional “four-division method” cannot verify the simultaneity of the line loss, and only the line loss analysis can be performed on the designated area. In addition, the statistical error of line loss is large, which is not in line with the flexible development characteristics of today's smart grid. Breaking the limitations of the four-division management and realizing the line loss calculation of any partition is conducive to the precise and flexible management of line loss.

The power stations, substation feeders and nodes equipped with measuring devices in the power grid can obtain real-time data such as voltage, active power, reactive power, and power factor [4]. However, due to different acquisition times and different periods of supply and sale of electricity, the data may not have simultaneity and affect the accuracy of line loss calculation. The traditional line loss calculation method is based on simplified approximation, and the data collected by the measuring device is not fully utilized, so that the line loss calculation result is not ideal [5]. In order to maximize the use of measurement data, it is necessary to overcome the simultaneity of the data, and repair the data missing from the meter.



Matpower is a software written in Matlab to solve power trends and optimize power flow problems. It provides a variety of power flow calculation methods, including the classic Newton-Raphson method, Gauss-Seidel method, and fast decoupling algorithm (XB version) and fast decoupling algorithm (BX version) [6,7]. It is only necessary to input the parameters of the grid and set accordingly, and the power loss in the network can be calculated from the power flow. The network information in Matpower is stored in the form of a matrix, which is easy to implement for reading, writing, modifying and segmenting network parameters, and has strong operability.

In view of the shortcomings of the existing line loss four-division management method and the limitations in the application, this paper has developed a corresponding data processing method with the goal of maximizing the measurement data. Combined with the advantages of Matpower processing multi-node complex system, the calculation method of arbitrary partition line loss of power grid using full measurement data is proposed, and the feasibility of the method is illustrated by actual cases.

2. Processing of measurement data

According to the time effect and real-time, the measurement data of the power grid is divided into two categories: one is real-time measurement data, which can reflect the real-time status of the grid to a certain time, such as voltage, current, line power, etc.; one is non-real-time measurement data, which mainly refers to data such as the quantity of electricity that reflects information within a certain period of time.

2.1. Simultaneous processing of data

Both types of data are subject to interference from simultaneous issues, affecting the use and mining of data.

For real-time measurement data, the problem of different periods is mainly due to the different sampling time of the real-time measurement meter, and there is a clock deviation in the sampling time of each meter. Figure 1 shows the power curve of i-node in one day, and its sampling time is later than the whole point. In this way, when calculating the line loss at the hour, the value used is collected at the previous time, which will bring errors to the line loss. For example, the data for its 12-point line loss calculation is 110kW. Using the method of interpolation [4], the data of different sampling moments of each measuring point is estimated to the data of the same time, in order to avoid the error caused by Non-simultaneity of real-time data. The results of the i-node data processing are shown in Fig. 2. Its 12-point line loss calculation uses real-time data of 100.7 kW, which greatly improves the accuracy.

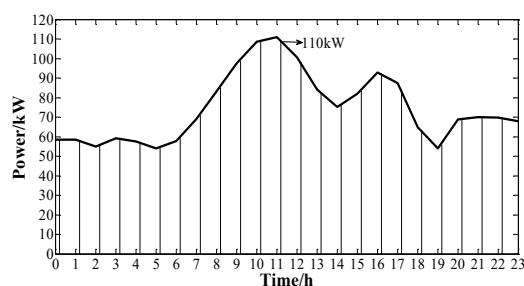


Figure 1. Power load curve of node *i*.

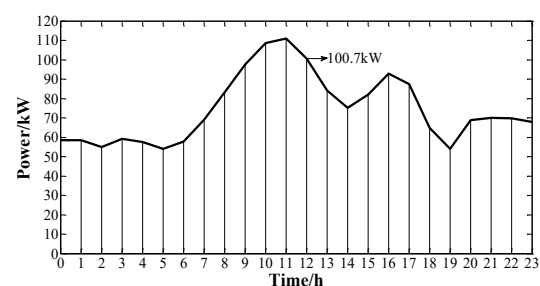


Figure 2. Power load curve of node *i* after processing.

For the quantity of electricity data, the main reason for its non-simultaneity of problems is the different periods of supply and sales statistics. In areas where traditional meter reading methods are used, due to the large number of users who need to go to the household to read the meter, it is difficult to achieve the same cycle statistics for electricity supply and sales. Only the meter reading time set by the power company can be strictly implemented to reduce the phenomenon of different periods as much as possible [8]. For the phenomenon of meter reading at different times that is difficult to avoid,

the quantity of electricity obtained by meter reading and the actual meter reading cycle can be used to reduce the error caused by different period statistics [9]. As shown in formula (1):

$$A_0 = A_1 \cdot \frac{T_0}{T_1} \quad (1)$$

In the formula, A_0 represents the actual monthly sales volume of quantity of electricity, A_1 represents the meter reading quantity of electricity, T_0 represents the actual monthly statistical days, and T_1 represents the meter reading statistics days.

2.2. Data processing for different types of nodes

According to the type of sampling data, the nodes are divided into three categories: one is a node that can collect real-time measurement data such as voltage and power, which is called a measurement node; another type of node does not have a collection terminal and can only obtain monthly quantity of electricity information through the electric energy meter, which is called electricity node; the last one is the node that can neither obtain the real-time measurement data nor the quantity of electricity information, and only knows its distribution capacity, which is called the capacity node [9].

On the basis of realizing the data synchronization processing, in order to make full use of the data collected by the monitoring device and realize the arbitrary partition line loss calculation based on the measurement data, it is necessary to obtain the real-time power values of each node, especially the electricity node and the capacity node. Corresponding data processing methods are proposed for different types of nodes.

The measurement node with the most detailed measurement data, the data processing target is to establish the load reference in each load mode as a reference node, and use the established reference to estimate the real-time injection power value of the remaining nodes. The injection power of the electricity node of the same load type as the measurement node can be estimated for the line loss calculation. Specific steps are as follows:

1) Calculate the daily quantity of electricity of the electricity node:

Calculate the power coefficient of the measured node, as shown in equation (2), which represents the load level on the representative day.

$$K_P^m = \frac{A_P^m}{[\sum_{i=1}^N A_{P,i}^m]/N} \quad (2)$$

$$K_Q^m = \frac{A_Q^m}{[\sum_{i=1}^N A_{Q,i}^m]/N}$$

In the formula, K^m is the power coefficients of the reference node m on the representative day; A^m is the quantity of electricity of the reference node m on the representative day; A_i^m is the quantity of electricity injected into the reference node m on the i -th day of the month; N is the number of days in the month. P, Q in the formula represent active and reactive variables.

Combine the monthly quantity of electricity information and the power coefficient of the reference node, and calculate the power consumption of the electricity node on the representative day by using equation (3), namely:

$$A_P^n = K_P^m \cdot \frac{A_{P,\Sigma}^n}{N} \quad (3)$$

$$A_Q^n = K_Q^m \cdot \frac{A_{Q,\Sigma}^n}{N}$$

In the formula, A_{Σ}^n is the monthly quantity of electricity of the electricity node n ; A^n is the quantity of electricity of the electricity node n on the representative day; N is the number of days in the month. P, Q in the formula represent active and reactive variables.

2) Calculate the average power of the reference node:

$$\begin{aligned} P_{av}^m &= \frac{A_P^m}{T} \\ Q_{av}^m &= \frac{A_Q^m}{T} \end{aligned} \quad (4)$$

In the formula, P_{av}^m and Q_{av}^m are the average power injected; A^m is the quantity of electricity of the reference node on the representative day; T is the measured hours, according to the actual situation, generally take 24 hours.

3) Calculate the ratio of injected power to average power at each time of the reference node:

$$\begin{aligned} K_{P,i} &= \frac{P_i^m}{P_{av}^m} \\ K_{Q,i} &= \frac{Q_i^m}{Q_{av}^m} \end{aligned} \quad (5)$$

Where P_i^m and Q_i^m are the power injected at the i -th moment of the reference node.

4) Using the analysis of the above power data, calculate the injection power at each moment of the electricity node.

$$\begin{aligned} P_i^n &= \frac{K_{P,i} A_P^n}{T} \\ Q_i^n &= \frac{K_{Q,i} A_Q^n}{T} \end{aligned} \quad (6)$$

Where P_i^n and Q_i^n are the injection power at the i -th moment of the electricity node n on the representative day; A^n is the quantity of electricity of the electricity node n on the representative day. For the capacity node, there are two practical data processing methods. The first one is to convert capacity nodes to electricity node processing. Calculate the total quantity of electricity of all capacity nodes by using the difference between the quantity of electricity of the line root node and the quantity of electricity of the remaining nodes, and allocate the total quantity of electricity to each capacity node according to the capacity ratio, so as to get the quantity of electricity of each node on the representative day.

$$\begin{aligned} A_P^r &= \frac{S_e^r}{\sum_{t_3} S_e^{t_3}} [A_P^0 - \sum_{t_1} A_P^{t_1} - \sum_{t_2} A_P^{t_2}] \\ A_Q^r &= \frac{S_e^r}{\sum_{t_3} S_e^{t_3}} [A_Q^0 - \sum_{t_1} A_Q^{t_1} - \sum_{t_2} A_Q^{t_2}] \end{aligned} \quad (7)$$

Where A^0 represents the quantity of electricity of the line root node; S_e^r is the rated capacity of the distribution transformer at node r ; t_1, t_2, t_3 are the collection of measurement nodes, electricity nodes, and capacity nodes, respectively.

The second method is to directly use the estimated power data. Directly use the total power of the root node minus the power of measurement node and the approximate power of the electricity node, and then allocate the node power according to the capacity ratio.

$$\begin{aligned} P_i^r &= \frac{S_e^r}{\sum_{t_3} S_e^{t_3}} [P_i^0 - \sum_{t_1} Q_i^{t_1} - \sum_{t_2} Q_i^{t_2}] \\ Q_i^r &= \frac{S_e^r}{\sum_{t_3} S_e^{t_3}} [Q_i^0 - \sum_{t_1} Q_i^{t_1} - \sum_{t_2} Q_i^{t_2}] \end{aligned} \quad (8)$$

Compared with method 1, method 2 has no node conversion process, and the calculation is simple. However, the second method uses the estimated data, which is not as accurate as the method one.

Based on the real-time injection power value of the measurement node, the above method can be used to estimate the injection power of the electricity node and the capacity node, and further provide reliable data support for the line loss calculation of any partition.

3. Line loss calculation for any partition

In the process of power flow calculation, the power grid is purposefully segmented to realize the line loss calculation of the region of interest, and the line loss management is more refined. It is the principle and purpose of calculating the arbitrary partitioning line loss in this paper.

3.1. Arbitrary partition line loss calculation model

On the basis of obtaining the approximate real-time power of each electricity node and capacity node, the measurement information of the node can be fully utilized to realize the calculation of the arbitrary partitioning line loss of the power grid.

Figure 3 is a partial schematic view of a grid partition. In the figure, m is the total number of boundary nodes of partition i and partition j , and x_i and x_j are the internal nodes of the i, j partition, respectively.

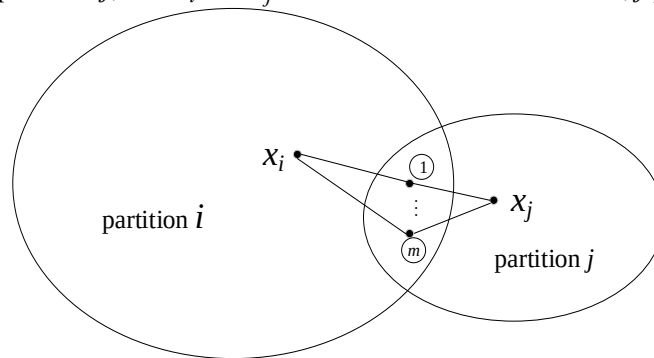


Figure 3. Schematic diagram of grid partition.

On the basis of obtaining the injection power of each non-real-time measurement node, the measurement information of the boundary nodes 1, 2, ..., m is utilized. According to the voltage level and the direction of the power flow, the lines connected to the boundary nodes of the upper power grid are equivalent to the load, and the line connected to the boundary node of the lower power grid is equivalent to the power supply. For the line whose current trend is uncertain, it can be temporarily used as a variable power supply.

For the partition i , as the upper-level power grid, the line connected to its boundary node is equivalent to the load. The load of each boundary node is expressed as:

$$P_{L,n} = P_{L,n}^0 + P'_{L,n} \quad (9)$$

Where $P_{L,n}$ represents the equivalent load of the boundary node n ; $P_{L,n}^0$ is the load that supplies power to the user; $P'_{L,n}$ is the sum of the power delivered to the other partitions.

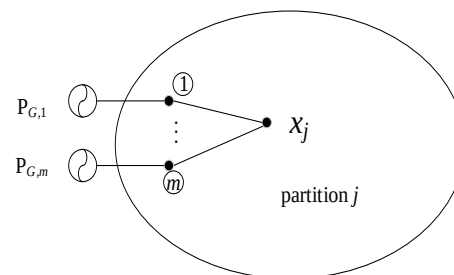
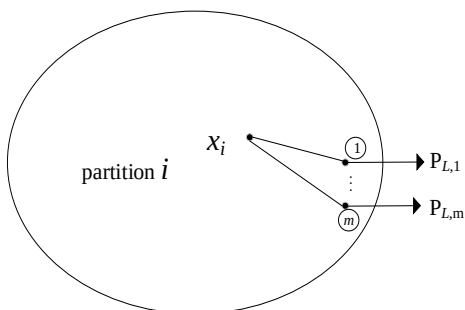


Figure 4. The equivalent result of the i partition **Figure 5.** The equivalent result of the j partition.

For the partition j , as the lower-level network of the power receiving end, the line connected to the boundary node is equivalent to the power supply. The input power of each boundary node is:

$$P_{G,n} = P_{G,n}^0 + P'_{G,n} \quad (10)$$

Where $P_{G,n}$ represents the equivalent input power of the boundary node n ; $P_{G,n}^0$ is the power generated by the generator connected to the node and the power generated by the distributed power source; $P'_{G,n}$ is the sum of the power delivered to it by the upper-level grid.

After obtaining the equivalent partitioning network, the theoretical line loss calculation of each partition can be carried out separately. In the partition calculation process, if the difference ΔP between the average power per hour of the node and the actual measured data of the measurement node is too large, the approximate injection power of the electricity node and the capacity node may be corrected and checked whether the capacity of each distribution transformer itself is exceeded. The result is considered accurate until ΔP is within the allowable range.

3.2. Calculation of arbitrary partitioning line loss based on matpower

In this paper, a simple operation software matpower is used to calculate the arbitrary partitioning line loss. Only the power supply, load and branch parameters of the power grid need to be input according to the specified format, and the power flow calculation result and line loss can be obtained [10]. The software is easy to apply and has high calculation accuracy.

The steps to build a matpower network computing model are as follows:

- 1) Set the network reference capacity and calculation mode. Normally, the system reference capacity is set to 100 MVA.
- 2) Construct a network node matrix, sequentially number each bus node of the power grid, and input the actual network data into each column of the matrix.
- 3) Construct a network power matrix. The nodes connecting the generators in the network are regarded as power supply nodes, and the nodes connected to the upper grid at the boundary are also regarded as power supply nodes.
- 4) Construct a network line matrix, determine the nodes connected at both ends of each route, and input information such as line impedance, admittance, and transformer ratio into the matrix.
- 5) According to the specified format, save the parameters in a project file under the matpower directory. After inputting the command, the program will automatically run the Newton method power flow calculation, and get the line loss of the network.
- 6) Based on the partition model described in the previous section, the data parameters are read and written to rewrite and divide the network parameters to realize the calculation of the arbitrary partitioning line loss of the network.

After the power grid is partitioned by manual decision, the boundary of each subnet uses the node measurement information as the power source and load equivalent. The subnets after the boundary is equivalent to the complete network, whether it is the node size, or the power and load parameters will change, you need to modify the parameters of the subnet.

First, the nodes included in the subnet are extracted according to the numbers to form a new network node matrix. Subnet generation can be achieved by deleting redundant nodes of the original network. For the power supply and load information of the subnet, based on the original node information of the subnet, the rewriting of the boundary node is implemented according to the measurement information of the boundary line. In this way, the line loss calculation of any partition is realized by generating a new subnet parameter matrix.

In the process of calculating the line loss of each partition, if the calculation does not converge, the subnet parameter matrix can be checked and a new matrix can be regenerated until the final solution of convergence is obtained.

The overall flow of the partition line loss calculation method proposed in this paper is shown in Figure 6.

4. Case analysis

Taking a power grid in a certain area of Gansu as an example, the method of this paper is used to calculate the line loss of any partition. The geographical connection diagram of the area network is shown in Figure 7. The power network spans two voltage levels of 110kV and 35kV, including 123 computing nodes, 174 transmission lines, and 43 substations. The data collection is 472,340, which is rich in measurement information.

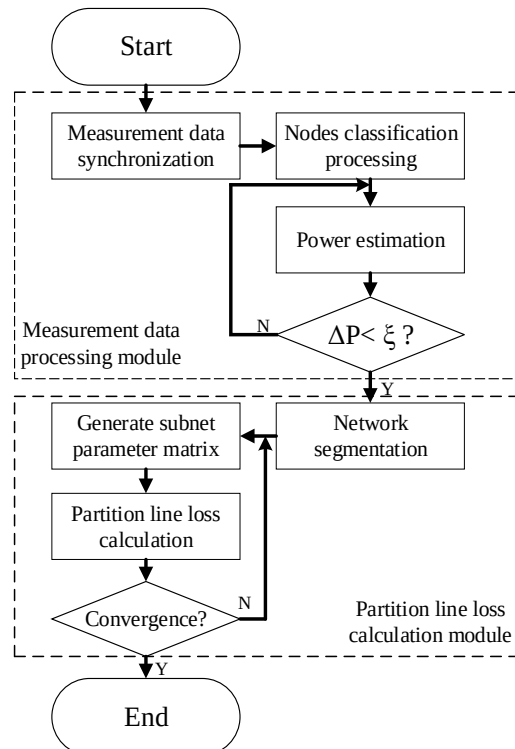


Figure 6. Line loss calculation process for any partition.

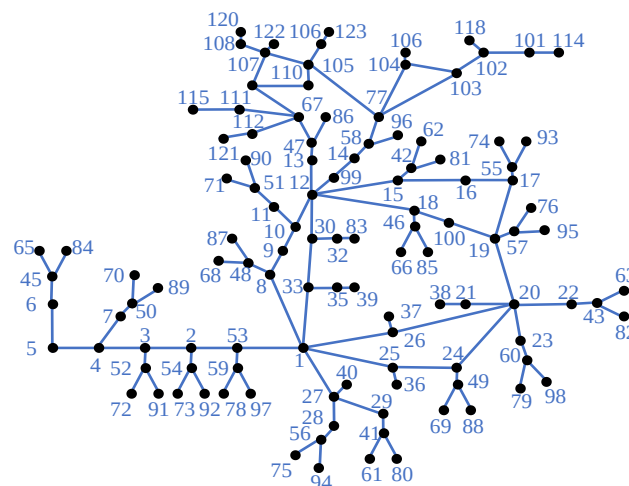


Figure 7. Electrical connection diagram of the area network.

After constructing the matpower 123-nodes network model in the region, the region of interest is selected and the system is divided into a 100-nodes system and a 23-nodes system. There are three boundary nodes in the two subnets, two of which are measured nodes, the node numbers are 66 and 67 respectively; one electricity node, the node number is 77.

The 66-node incoming and outgoing line power and load can be obtained from the measurement information, which are $3.294+j0.386$ MVA, $3.293+j0.387$ MVA and 0MVA respectively. The node is equivalent to a load node in the upper-level power grid, and its equivalent load is the sum of the outgoing power and the user load, which is $3.293+j0.387$ MVA; in the lower-level power grid, it is equivalent to the power supply node, and its equivalent power is the incoming line power, which is $3.294+j0.386$ MVA. The same is handled for the 67 node that are the same measurement nodes.

For the 77 electricity node, because of the lack of measurement information of the incoming and outgoing line power, it is necessary to use the measurement node as a reference for power estimation. The resulting incoming and outgoing line powers were estimated to be $12.563 + j3.772$ MVA and $12.563 + j3.771$ MVA by the method described in Chapter 2. Equivalent to the load node of the upper-level power grid, the equivalent load is $12.563+j3.771$ MVA; equivalent to the power supply node of the lower-level power grid, the equivalent power supply is $12.563+j3.772$ MVA.

After the equivalent processing of the boundary nodes of the two subnets, the node matrix of each subnet can be derived, and the power and load information of each subnet can be corrected. Finally, the power flow of each partition is converged, and the line loss of the partition is calculated. Figures 8 and 9 show the calculated voltage and power for each node. Table 1 shows the calculation result. Table 2 compares the calculation results of the method with the conventional method. The results show that the method is highly accurate when calculating the arbitrary partition line loss of the grid. The method of this paper is very feasible.

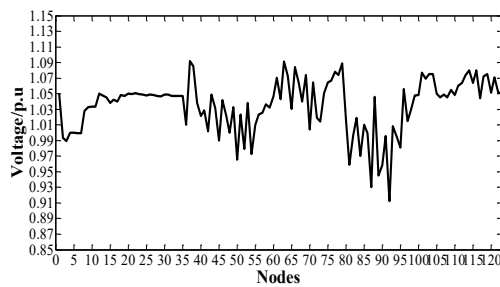


Figure 8. Voltage amplitude of each node of the power grid.

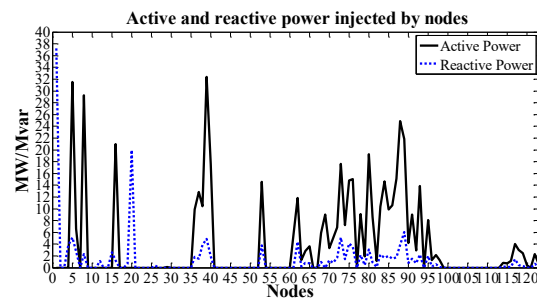


Figure 9. Active power and reactive power of each node.

Table 1. Line loss calculation result

Power network	Active loss(MW)	Reactive loss(Mvar)
100-nodes network	4.094	41.53
23-nodes network	0.864	4.271
Total network	4.958	45.801

Table 2. Comparison of calculated results between proposed method and conventional method

	Active loss(MW)	Reactive loss(Mvar)
Conventional method	4.967	45.54
Proposed method	4.958	45.801
Deviation	0.18%	0.57%

5. Conclusion

In order to adapt to the flexible and changeable development characteristics of the smart grid, it is necessary to break the limitation of the four-division line loss management, realize the transition to arbitrary partition management, and flexibly and effectively select any region for line loss analysis. Based on the data synchronization process, this paper classifies each node to estimate the injected power value of each node. Make full use of measurement information, combined with matpower's convenient power flow calculation and easy-to-modify network parameters, realize line loss calculation in any partition. This method has no redundant calculation, simple and efficient, and provides a new idea for line loss management in any partition of smart grid. The case analysis shows that the method is very feasible.

Acknowledgments

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