

Recognition of Station Topology Based on Power Conservation

Yulu Cai*, Yuhu Nie, Wenpeng Cui, Rui Liu, Zhe Zheng, Jingyi Yu

Beijing SmartChip Microelectronics Technology Company Limited Beijing, 100192, China

*Corresponding Author.

Abstract

Aiming at the problems of the confusion of user meter data in the distribution network and the difficulty in identifying the relationship, a creative method of identifying the topological structure of the station based on the conservation of current and energy is proposed. Through the calculation of the current data relationship, a mathematical relationship model based on energy conservation is established for the topological scene of the station. After constructing the mathematical model, through a series of transformation methods, the model is transformed into a convex optimization problem. By solving the model, the topological relationship of the station is finally obtained. Through the experimental verification and analysis of real data, the model algorithm proposed in this paper has higher accuracy and higher efficiency than manual screening, and has deeper research value.

Keywords: Platform topology, calculation model, energy conservation, machine learning

I. Introduction

In power system, a station refers to the power supply range of a transformer. The topological structure of the station refers to the number of machines belonging to each transformer and its control range, which is an important condition for the power supply department to analyze the line loss and fault range. Low-voltage substation is the final link of distribution network power supply, with many types of loads and weak wiring rules. With the accelerated expansion and development of power system, the residential power load is accelerating. There are numerous low-voltage distribution networks deployed in residential areas and office areas in various cities, with increasingly complex structure and frequent adjustment. As a result, problems such as the discrepancy between the electric energy meter file and the reality, and the difficulty in defining the attribution of the user station are emerging [1]. At present, the topological relationship between users, troubleshooting and maintenance mainly rely on manual operation, which consumes lots manpower and material resources with low efficiency and is difficult to meet the requirements of low-voltage power supply station. Therefore, how to build an intelligent method of station topology recognition and improve work efficiency is one of the research hotspots in current power system.

In view of the existing problems in the current low-voltage station topology, scholars at home and abroad have carried out a series of studies. Yang Zhichun [2] et al. put forward a topology identification method of low-voltage distribution network based on data association analysis, which screens characteristic voltage series in each type of station and calculates the correlation and non-correlation among distribution transformers, branch boxes, meter boxes and intelligent watt-hour meters in each group by using Tanimoto similarity coefficient to realize the topology identification of low-voltage distribution network. Li Ning [3] et al. proposed an on-line generation method of power topology structure in low-voltage substation based on power measurement data. Liang Xuchang [4] et al. put forward a topological combing analysis method of big data station based on the principle of conservation of electricity. Zhang Pan et al. put forward a technology of subscriber transformer identification and phase identification based on broadband carrier communication. Wang Rining et al [5] proposed a topology recognition method for distribution network station based on intelligent terminal characteristic signals.

The existing method of station topology identification requires numerous complicated data collection processes. Sometimes it is difficult to realize access to households, and it is necessary to add meters and other equipment and

invest more manpower and funds to support it.

In this paper, a new model of station topology recognition is proposed. A simple physical model is constructed by the law of conservation of current, and the station recognition is transformed into a convex optimization problem, which can significantly reduce the labor and equipment costs and improve the recognition accuracy.

II. Low-voltage Distribution Network

The power system can be divided into three major components: power generation, transmission and distribution. The electric energy of the power generation system is transmitted through the transmission system and distributed to each user through the distribution system. As the last link of the power system, the distribution system directly faces the end users, so its improvement is directly related to the reliability and quality of power consumption of the vast number of users. It plays an important role in the power system [6]. The low-voltage station refers to the area below the 10KV/400V transformer. After the 10KV voltage is reduced to 400V by the transformer, the electric energy is distributed to different users through branch feeders.

Figure 1 is the schematic diagram of power supply in the lower substation. As shown in the figure, there are switch 1, switch 2, switch N under the transformer, and there are different number of meter users under different switches.

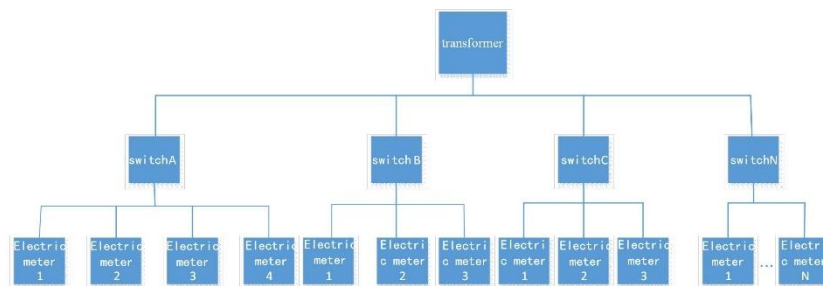


Fig 1 Schematic diagram of power supply in low voltage station

III. Research on Topological Structure Model of Two Stations

In this paper, the principle that the current remains unchanged under the premise of constant voltage and resistance in physics, and the basic principle that the sum of branch currents equals the trunk current are used in the modeling of the station. Then, using the mathematical linear theory analysis and referring to the model solving method of the perceptron in machine learning, the model structure with the least loss is finally obtained, which reflects the positioning of the meter in the station.

3.1 Research on mathematical basis of modeling

3.1.1 Kirchhoff's current law

Kirchhoff's current law, that is, node current law, means that at any time, the sum of currents flowing into a node is equal to the sum of currents flowing out of the node. Namely:

$$\sum_{k=1}^n I_k = 0 \quad (1)$$

Wherein, I_k refers to the k th current entering or leaving this node and the current flowing through the k th branch connected with this node, which can be a real number or a complex number.

Therefore, in the station, if the above relation is satisfied in a line, it means that these electrical appliances belong to

a trunk road and belong to the same user. Then, the topological relationship corresponding to this data set is the correct user-transformer relationship in this station.

3.1.2 Perceptron model

The perceptron model is a linear model for binary classification. Its input is the feature vector of an instance, and its output is the category of the instance. The perceptron divides the instance into positive and negative separation hyperplanes corresponding to the feature space, which belongs to the discriminant model.

It is assumed that there are n samples, and each sample corresponds to the m -dimensional feature and a binary category output. As follows:

$$(x_1^{(0)}, x_2^{(0)}, x_3^{(0)}, \dots, x_m^{(0)}, y_1), (x_1^{(1)}, x_2^{(1)}, x_3^{(1)}, \dots, x_m^{(1)}, y_1), \dots (x_1^{(n)}, x_2^{(n)}, x_3^{(n)}, \dots, x_m^{(n)}, y_n) \quad (2)$$

The goal is to find a hyperplane so that:

$$\theta_0 + \theta_1 x_1 + \dots + \theta_m \quad (3)$$

If the data is linearly separable, such hyperplane is generally not unique, which means that the perceptron model can have multiple solutions.

To simplify the writing of this hyperplane, a feature $x_0=1$ is added to obtain the hyperplane as follows:

$$\sum_{k=1}^n \theta_i x_i = 0 \quad (4)$$

3.1.3 Equality constraint optimization

The main method to solve the equality constraint is to determine the gradient of Newton's method by KKT condition, so that the gradient satisfying the equality constraint can be obtained, and further iterative optimization can be carried out by using the method.

Equality constraint optimization can be written as:

$$\begin{cases} \text{minimize } f(x) \\ \text{subject to } Ax = B \end{cases} \quad (5)$$

According to the equality constraint and after substituting the objective function into KKT condition, the derivative of the above formula can be converted into matrix form to obtain the solution.

3.1.4 Loss function

Loss function mainly includes SSE, MSE, PMSE, etc. In statistics, SSE parameters are used to calculate the sum of squares of errors between fitting data and original corresponding points. The calculation formula is:

$$SSE = \sum_i 1^m w_i (y_i - y_i^f)^2 \quad (6)$$

y_i is real data and y_i^f is fitting data, $w_i > 0$. The closer the SSE value is to 0, the better the fitting result of the model is.

MSE is the mean value of the sum of squares of errors at corresponding points of predicted data and original data. Assuming that n is the number of samples, MSE can be expressed as follows:

$$MSE = \frac{SSE}{n} = \frac{1}{n} \sum_i = \frac{1}{n} \sum_i w_i (y_i - y_i^r)^2 \quad (7)$$

3.2 Modeling

The left half of Figure 1 is cut out to get Figure 2 below. Y represents the current on the trunk line, and $x_1, x_2, x_3 \dots x_n$ represents the current of electrical appliances 1, 2, 3 ... n , respectively, which shows the following relationship:

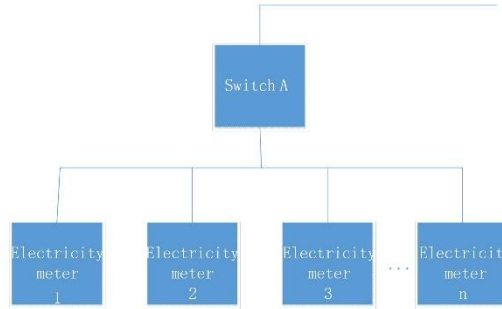


Figure 2 Topology diagram of single switch with multi-meters

$$y = x_1 + x_2 + x_3 + \dots + x_n \quad (8)$$

Since it is uncertain whether the electrical appliances on each branch are in use or in a power consumption state, the parameter a ($a = 0/1$) can be added to the above formula. Then, the above formula is transformed as follows.

$$\begin{cases} y = a_1 x_1 + a_2 x_2 + \dots + a_n x_n \\ a = 0/1 \end{cases} \quad (9)$$

It can be written as follows:

$$\begin{cases} y = a_1 x_1 + a_2 x_2 + \dots + a_n x_n \\ y = a_1^2 x_1 + a_2^2 x_2 + \dots + a_n^2 x_n \end{cases} \quad (10)$$

3.3 Definition of model loss

For mula 10 can be written as follows. It can be seen that Formula 11 can be regarded as a perceptron model.

$$y = \frac{1}{2} \sum_{k=1}^n (a_k x_k + a_k^2 x_k) \quad (11)$$

Assuming that y_k is the measured trunk current value and y_{k_pred} is the predicted trunk current value. The difference between the expected measured current value and the expected current value should be as small as possible. The mean square error (MSE) is used here to solve the error, which can be expressed by loss as follows:

$$loss = \frac{1}{2} \sum_{k=1}^n (y_k - y_{k_pred})^2 = \frac{1}{2} \sum_{k=1}^n (y_k - a_k x_k - a_k^2 x_k) \quad (12)$$

Then, the problem for solving is transformed into the problem of finding the minimum value of loss. The formula is used to solve the partial derivative for a_k :

$$\text{Loss}_{a_k} = -2(y - y_{pred}) \sum_{k=1}^n (x_k + 2a_k x_k) \quad (13)$$

3.4 Analysis of influencing factors

The regular behavior of users in the station leads to the similarity of their behavior habits in electricity consumption, indirectly leads to the similarity of electricity consumption data of different users, and brings uncertainty in calculation as well as difficulties to the identification of the topological structure in the station [7][8]. The factors affecting station identification mainly include the following aspects:

- (1) When the electrical equipment of users in the station breaks down, or the electricity meter is replaced, or there is electric leakage of electricity meter, there will be user missing in the station, which will cause the loss of accuracy [9].
- (2) When a user steals electricity maliciously, the measured current data will be inaccurate, which leads to the decrease of accuracy of station identification [10].
- (3) When the communication state of the electric meter on the electric equipment of the users in the station is unstable, there will be data missing in the process of data statistics, which will affect the accuracy.

IV Experiment and Analysis

4.1 Model solving

In 2.3, we define the loss of the model. Assuming that the vector matrix composed of parameter a_k is W , and the update expression of W is:

$$w_{k+1} = w_k + 2(y - y_{pred}) \sum_{k=1}^n (x_k + 2a_k x_k) \quad (14)$$

4.2 Experimental data

The data in this experiment are collected independently. The collection method is as follows: collecting the current at the switch and the electricity meter respectively at the same time, with collection time of 15 minutes/time.

4.3 Analysis of experimental process

4.3.1 Solution of single switch circuit

As shown in Figure 3, there are three meter users under switch A, namely, meter 1, meter 2 and meter 3. If meter 3 is disconnected from the trunk road due to failure, then

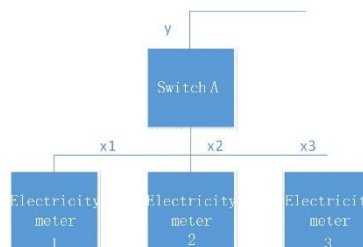


Figure 3: Topology structure diagram under single switch structure

Table 1: Calculation result of coefficient under single switch

	a_1	a_2	a_3	a_1
Switch A	9.928955 41e-01	1.0058413 3e+00	-9.616625 02e-06	Switch A

According to the experiment, when there is no missing meter data, the obtained parameters are all very close to 0 or 1. In case of missing meter data, the formula cannot be established, which leads to inaccurate experimental results (as is shown in Table 1).

4.3.2 Solution of multi-switch circuit

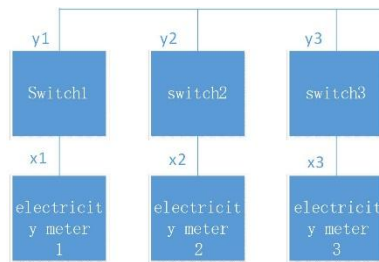


Figure 4 Topology structure diagram of multi-switch single meter

As shown in Figure 4, when there are multiple switches under the transformer and there are single meter users under each switch, the experimental results are shown in Table 2 below.

Table 2: Calculation results of coefficients under multiple switches

	a_1	a_2	a_3
Switch 1	9.92895541e-01	1.00584133e+05	-9.61662502e-06
Switch 2	-3.78098627e-01	8.37088346e-01	3.93420813e-01
Switch 3	-1.02904999e-0	9.18581750e-02	9.92774539e-01

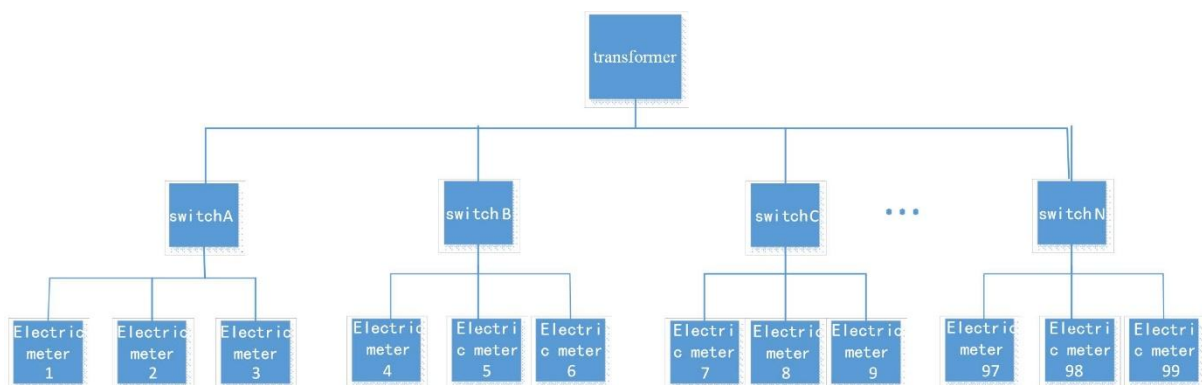


Figure 5 Topology structure diagram under multiple switches and multiple meters

As shown in Figure 5, when there are 33 switches under the transformer and there are 3 meter users under each switch, there are 99 meter users in total. In this case, the experimental results are shown in Table 3 below.

Table 3: Calculation results of coefficients under multiple switches and multiple meters

	a_1	a_2	...	a_{99}
Switch A	9.11e-01	9.99e-01		8.11e-6
Switch B	-8.55e-06	-1.64e-06		9.11e-7
Switch C	-9.99e-06	-8.99e-05		9.16e-7
Switch N	-9.55e-06	-9.78e-06		1.00e+00

4.4 Analysis of experimental results

Through the analysis of the experimental results, it can be concluded that: when there is no missing meter data, the obtained parameters are all very close to 0 or 1. If the parameter values are not very close to 0 or 1, voltage correlation can be carried out for verification of meters. If the correlation is less than the threshold, it indicates missing meter data.

V. Conclusion

The principle of current conservation is very simple. Based on this, this paper establishes relevant mathematical models and solve them, so as to quickly and accurately obtain the topological structure of complex stations.

This technology is an innovative technology, and there is still room for improvement. In addition to low-voltage station topology, it also has many other application fields, with strong generalization performance and universality.

Acknowledgements

Funded by the State Grid Corporation Headquarters Science and Technology Project: Research on key technologies of ultra-lightweight AIoT chips for terminal-side electrical parameter analysis (5700-202016489A-0-0-00).

References

- [1] Yu. Y. X, Luan. W. P, Review of smart grid. Proceedings of the CSEE, 2009, 29(34):1-8. Ge Nianming, Yin Caiping, Shao Wenxue. Design of indoor harmful gas detection system based on STM32. Information Technology and Network Security, 34 (23), 2015.
- [2] Yang. Z. C, Shen. Y, Yang. F, Le. J, Su. L, Lei. Y, Topology identification method of low-voltage distribution network based on data association analysis. Electrical Measurement & Instrumentation, 57(18). 5-11+35, 2020.
- [3] Li. N, Guo. Z. L, Yuan. T. J, Wang. Y. C. Bai. Y. P, Pan. C. L, Yan. Q, Power topology generation method in low voltage area based on power measurement information. Distributed Energy, 5(05). 48-55, 2020.
- [4] L. X. C, Wang. Y, Huang. Z.P, Jin. G, Liu. L, Wang. P, Lin. J. D, Research and application of station topology calculation model based on electricity conservation principle. Power Systems and Big Data, 23(08). 79-85, 2020.
- [5] Zhang. P, Gao. Q. W, Huang. X, Zhu. C, Sun. W. Q, Topology identification method of low-voltage distribution network based on power carrier communication. Chinese Journal of Electron Devices, 44(01). 162-167, 2021.

- [6] Wang. R. N, Wu. Y, Wei. H. M, Wang. C. W, Distribution network topology recognition method based on intelligent terminal characteristic signal. *Power System Protection and Control*, 2021, 49(06), 83-89.
- [7] Li. Y, Liu. L. P, Li. B. Q, Yi. J, Wang. Z. Z, Tian. S. M, Calculation method of station line loss rate based on improved K-Means clustering and BP neural network. *Proceedings of the CSEE*,36(17). 4543-4552, 2016.
- [8] Xue, Y. S, Lai. Y. N, Integration of big energy thinking and big data thinking (I) Big data and Power Systems and Big Data. *Automation of Electric Power Systems*, 40(01).1-8, 2016.
- [9] Geng. J. C, Wu Bo, Wan. D. N, Yuan. S. G, Topology verification of low-voltage distribution network based on outlier detection. *Electric Power Information and Communication Technology*, 15(05). 61-65, 2017.
- [10] Milioudis. A. N, Andreou. G. T, Labridis. D. P, Enhanced protection scheme for smart grids using power line communications techniques—Part II: Location of high impedance fault position. *IEEE*.