Phase Identification of Low-Voltage Users with Novel Grey Relational Analysis Method

Guowei Zhao*, Rui Zhao¹, Yuanjie Gu¹, Bo Chang¹, Changlong Hu¹, Yang Xue¹

State Grid Shanxi Electric Power Company Datong Power Supply Company, Shanxi Province, 037008, China

*Corresponding author’s e-mail: zhao_guo_wei@163.com

Abstract. With the development of smart grid, the extensive use of advanced metering infrastructure (AMI) equipment further improves the lean management level of grid, which makes it possible to accurately analyse the power consumption information of low-voltage users. This paper proposes a novel algorithm for accurately identifying the phase of low-voltage users. The algorithm is based on grey relational analysis (GRA). Data collected from independent users and buses are used for comparative analysis by proposed algorithm. In this paper, the algorithm and its experimental results in Hebei Province are introduced in detail. The results show encouraging results that the proposed algorithm can accurately identify the low-voltage users’ electricity phase, and the performance of the improved GRA algorithm is better than the traditional GRA. The proposed method also has better effect compared with other methods of phase identification.

1. Introduction

The popularization of AMI technology promotes the development of smart grid[1]. Large-scale deployment of smart meters has also enabled grid managers to obtain a large number of high-quality data at the end of the distribution network[2]. It is helpful to improve the efficiency of power grid by analysing these data [3-8].

A lot of research focuses on the phase identification of low-voltage users at present. Arya sums the power consumption data of each independent user and compares the results with the data obtained at the transformers and substation so as to realize the phase identification. This method needs to solve the generated linear equations to improve the complexity of the algorithm [9]. The complexity of the algorithm is improved, because this method needs to solve the generated linear equations. Short proposes a method of signal injection to improve the accuracy of identification [10]. But this method needs different devices to realize signal injection and detection of injected signal, which undoubtedly increases the cost.

For the limitations of the above methods, this paper proposes a user phase identification method based on improved GRA. The contributions and emphases of this paper are as follows: (1) the GRA is applied to the phase identification of user power consumption. This method can realize the phase identification without prior data. It has the advantages of small calculation amount, high accuracy and no need for the topological diagram of distribution network; (2) the algorithm is improved on the basis of the traditional GRA.

The remainder of the paper is organized as followed: Section 2 describes the limitations of the traditional GRA and the improvement of GRA in this paper; in Section 3, the user phase identification...
method based on improved GRA is described; the experimental results are shown in Section 4; the
discussion and conclusion are summarized in Section 5.

2. The phase identification method based on GRA mode
GRA is an important part of grey system theory[11]. By comparing geometric similarity, the degree of
correlation between sequence curves is obtained. On the problem of phase identification of user power
consumption, the phase information collected at bus is determined by the power consumption data of
independent users in each phase. We can judge the phase of the independent user according to the
similarity between the power data of the independent user and the power data of each phase on the bus.
Thus, the GRA can be used for phase identification. In addition, we improved the GRA.

Suppose that the main sequence and the sub-sequence are $Q_M \in R^v$ and $Q_S \in R^v$, respectively. The
$Q_M$ and $Q_S$ are need to be processed of dimensionless. Dimensionless processing methods include
initial transformation, multiple transformation and el. [12]. In this paper, dimensionless processing
adopts the initial transformation method. It can be expressed in the following equations:

$$Q_M^0 = [q_M^0(1), \ldots, q_M^0(n)] = [q_p(1)\varepsilon, \ldots, q_p(n)\varepsilon]$$

(1)

$$Q_S^0 = [q_S^0(1), \ldots, q_S^0(n)] = [q_S(1)\varepsilon, \ldots, q_S(n)\varepsilon]$$

(2)

where, $n \in N$ is the sequence length, $\varepsilon$ is the transformation operator based on percentage
transformation, which can be expressed by the following equation:

$$q^0(\phi) = q(\phi)\varepsilon = \frac{q(\phi)}{\max_{1\leq \phi \leq n} q(\phi)}$$

(3)

In the improved GRA, the gradient change within the sequence is introduced. It can be calculated
by the Equation (4):

$$\Delta \alpha(m) = |q^0(m+1) - q^0(m)|, m = 1, \ldots, n - 1$$

(4)

In order to avoid the influence of other variables in the subsequence, the proposed method only
calculates the correlation when the main sequence changes. In this paper, the grey correlation
coefficient is calculated by the following equation:

$$\gamma_{M,S}(m) = \text{sgn} \left( \frac{\Delta \alpha_S(m)}{\Delta \alpha_M(m)} \right) \min \left( \frac{\Delta \alpha_S(m)}{\Delta \alpha_M(m)}, \frac{\Delta \alpha_M(m)}{\Delta \alpha_M(m)} \right)$$

(5)

where, $\xi > 0$ is the threshold of the change range of the main sequence. Assuming that the number of
values satisfying $\Delta \alpha_M(m) > \xi$ is $T$, the correlation coefficients (CC) of the main sequence and the
subsequence can be obtained from the equation:

Based on the above definition, it can be known that $0 < |\gamma_{M,D}(m)| < 1$. When the main sequence and
the subsequence change at the same time and the absolute value of the change is same, $|\gamma_{M,D}(m)| = 1$.
In the improved GRA, the correlation is only related to the change of relative slope of sequence curve.
Therefore, the grey correlation coefficient calculated by the improved GRA algorithm is only related
to the geometric relationship between the main sequence and the sub-sequence.

3. Experiment Design
The experiment is carried out on the actual data collected from Hebei Province. The collected user
data is taken as the main sequence, and the electricity data of each phase measured at the bus is taken
as the sub-sequence. The improved GRA is used to calculate the grey correlation coefficient between
the main sequence and the sub-sequence. The obtained grey correlation coefficient can be used to identify the user phase.

The grey correlation coefficient between each phase data measured at the bus and users’ power consumption data is calculated to judge the similarity between data. The collected user data is taken as the main sequence, and the electricity data of each phase measured at the bus is taken as the sub-sequence. The grey correlation coefficient between main sequence and sub-sequence are obtained by Equation (5). The form of the sub-sequence is as follows:

\[
(X_a, X_b, X_c) = \begin{pmatrix}
X_{a1} & X_{b1} & X_{c1} \\
X_{a2} & X_{b2} & X_{c2} \\
\vdots & \vdots & \vdots \\
X_{an} & X_{bn} & X_{cn}
\end{pmatrix}
\]  

(6)

where, \(X_a, X_b, X_c\) are the data collected in the A phase, B phase, C phase, respectively. The phase most associated with the main sequence is considered to be the user's phase.

4. Experimental Result

To verify the practicability of the proposed method, data collected from Hebei Province are used for experiments. The actual data contains data under 4 transformers. For each transformer, each individual user is included in each phase. The summary of the collected data is shown in the Table 1.

| Table 1. The summary of the collected data |
|--------------------------------------------|
| Phase A | Phase B | Phase C | Total |
|-----------------|-----------------|-----------------|-----------------|
| Transformer 1   | 36              | 5               | 65              | 106             |
| Transformer 2   | 10              | 32              | 57              | 99              |
| Transformer 3   | 17              | 11              | 5               | 33              |
| Transformer 4   | 44              | 6               | 2               | 52              |

Figure 1 shows the data collected at bus of different phase under transformer 1 and the power consumption curve of phase A users under transformer 1. The solid line represents the bus data of phase A, and the dotted line represents the power consumption data of independent users under phase A. From Figure 1, we can see that the electric energy consumption data at phase A has a similar gradient change with the electric energy consumption data of user under Phase A.

![Figure 1. Power consumption data of A phase data and its independent user](image)

Table 2 shows the accuracy of the proposed algorithm for the identification of user phases under different transformers. From the table, we can see that the proposed method can effectively identify user phase.
Table 2. The identification accuracy of the proposed algorithm

| Transformer  | A phase     | B Phase     | C Phase     |
|--------------|-------------|-------------|-------------|
| Transformer 1| 0.95±0.01   | 0.97±0.01   | 0.98±0.003  |
| Transformer 2| 0.93±0.002  | 0.94±0.01   | 0.95±0.01   |
| Transformer 3| 0.92±0.02   | 0.95±0.03   | 0.95±0.04   |
| Transformer 4| 0.96±0.001  | 0.94±0.01   | 0.85±0.01   |

5. Conclusion
GRA and phase identification are naturally appropriate. There are two contributions in this paper, listed as followed: (1) the GRA is applied to the phase identification of user power consumption. This method can realize the phase identification without prior data. It has the advantages of small calculation amount, high accuracy and no need for the topological diagram of distribution network; (2) the performance of the algorithm is improved on the basis of the traditional GRA.

In this paper, the adopted method is improved on the basis of traditional GRA. Compared with the traditional GRA, the improved method is superior to the traditional GRA in identification accuracy.

Acknowledgments
This research was funded by [Science and technology project of State Grid Shanxi Electric Power Company. Fast non-intrusive load identification technology for non-residential users] grant number [5205B01800C5].

References
[1] Tang, X., Milanović, J. (2018) Phase Identification of LV Distribution Network with Smart Meter Data. In: 2018 IEEE Power & Energy Society General Meeting. Portland.
[2] Deka, K., Backhaus, S., Chertkov, M. (2016) Estimating distribution grid topologies: A graphical learning based approach. In: 2016 Power Systems Computation Conference, Genoa.
[3] Luan, C., Sharp, D., LaRoy, S. (2013) Data traffic analysis of utility smart metering network. In: Proc. IEEE Power Energy Soc. Gen. Meeting, Vancouver.
[4] Wang, Z., Begovic, Z., Wang, J. (2014) Analysis of conservation voltage reduction effects based on multistage SVR and stochastic process. IEEE Trans. Smart Grid. 5: 431-439.
[5] Hong, T., Burke, J. (2010) Calculating line losses in smart grid: A new rule of thumb. In: Proc. IEEE Power Energy Soc. Transmiss. Distrib. Conf. Expo., New Orleans, LA.
[6] Jayadev P, S., Rajeswaran, A., Bhatt, N., Pasumarthy, R. (2018) Identifying Topology of Low Voltage (LV) Distribution Networks Based on Smart Meter Data. IEEE Trans. Smart Grids. 9: 5113 – 5122.
[7] Wu, X., Gao, Y.C., Jiao D. (2019) Multi-Label Classification Based on Random Forest Algorithm for Non-Intrusive Load Monitoring System. Processes. 7:337.
[8] Xu, M., Li, R., Li, F. (2018) Phase Identification with Incomplete Data. IEEE Trans. Smart Grids. 9: 2777 - 2785.
[9] Arya, V., Seetharam, D., Kalyanaraman, S., Dontas, K., Pavlovski, C., Hoy. S., Phase identification in smart grids. (2011) In: 2011 IEEE International Conference on Smart Grid Communications. Brussels.
[10] Short, T. A. (2013) Advanced Metering for Phase Identification, Transformer Identification, and Secondary Modeling. IEEE Trans. Smart Grid. 7: 651-658.
[11] Deng, J. L. (1989) Introduction to grey system theory. J. Grey Syst. 1: 1-24.
[12] Dang, Y., Liu, S., Liu, B., Mi, C. (2004) Improvement on degree of grey slope incidence. Eng. Sci. 6: 41-44.