Research on typical application in distribution station area

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Abstract: The traditional power distribution station area lacks advanced functions for power distribution, and it is not conducive to operation and maintenance management. In order to improve the intelligent level of the distribution station area, it is constructed around with the intelligent distribution transformer terminal. Take intelligent distribution transformer terminal as the centre, the schemes of some typical applications, such as topology identification, line impedance analysis and three-phase unbalanced governance, are researched and designed to support the construction of distribution station area.

1. Introduction

As the power supply link directly facing the power user terminal, the distribution station area is related to the safety and reliability of power users. Under the pressure of high-level power supply service requirements and electric energy substitution, the business of distribution area is facing new challenges.

The traditional distribution station area terminal mainly collects the user's power consumption information, and the low-voltage operation and switch equipment information access in the station area is less, only relying on the main distribution station to carry out the analysis and processing of individual business. Due to the simple business function and low efficiency, the distribution system from distribution transformer outgoing line to user meter is basically in the blind area of monitoring. It is unable to realize the business management and control such as full condition monitoring, fault location and line loss analysis of low-voltage access equipment in substation area. Most of the work still relies on manual analysis, which not only causes the waste of human and material resources, but also affects the power supply reliability of distribution station area, it is not convenient for operation and maintenance management [1~2].

In recent years, the concept of edge computing of Internet of things is gradually applied in the distribution network, which provides ideas for solving the problem of distribution station area: building intelligent distribution station area, taking the intelligent distribution transformer terminal as the local data processing center, carrying advanced business applications, realizing online monitoring, intelligent analysis and decision-making control of the operation status of the station area.

2. The structure of distribution area

All kinds of low-voltage sensing devices are deployed at the distribution transformer side, low-voltage side and user side respectively in the distribution station area (Fig.1). The intelligent distribution transformer terminal is used as the center to collect and monitor the distribution transformer, low-
voltage branch box, low-voltage user operation electrical data, electric energy data and other information, and then the data in the station area is analyzed, calculated and sorted on demand through the intelligent distribution transformer terminal and sent to the main distribution station [3].

2.1. Intelligent distribution transformer terminal
The intelligent distribution transformer terminal adopts the domestic industrial level dual core chip which is safe, independent and controllable, and the main frequency is 1GHz. It includes RS485, HPLC, LoRa, LTE, FE electrical or optical port, and can collect AC voltage and current value. At the same time, the container technology of LXC is built in the intelligent terminal, which can support flexible configuration of all kinds of applications, and conduct comprehensive analysis and intelligent decision on the data of local collection.

![Fig.1 Composition of distribution station system](image)

2.2. Local equipment

2.2.1. Distribution transformer and low voltage side equipment. These equipment mainly includes the transformer at the low voltage side of the distribution transformer, intelligent sensing element, low voltage intelligent switch, intelligent monitoring device, multi-function instrument, which can monitors the electric quantity, switching quantity, non-electric quantity and other data in the distribution station area, and controls the opening and closing of the low voltage intelligent switch [4].

2.2.2. Low voltage line side equipment. These equipment mainly includes low-voltage fault sensors, which can monitor the electrical, switching and non-electrical quantities of low-voltage lines, actively report the low-voltage fault events and locations, and realize the dynamic topology identification and line loss impedance analysis of low-voltage distribution network.

2.2.3. End user side equipment. These equipment mainly includes intelligent commutation switch, fault sensor, intelligent monitoring device, smart meter, which can realize the functions of real-time data acquisition for low-voltage users, power failure event reporting, automatic load commutation.
2.3. Communication system.

2.3.1. Remote communication network. It mainly meets the communication requirements of high reliability, low delay and differentiation between IoT management platform and edge IoT agents [5]. Communication modes mainly include fibre-optical, power wireless private network, wireless public network.

2.3.2. Local communication network. It mainly meets the communication needs between the edge IoT agent and the acquisition terminal. The communication modes mainly include HPLC, RS485, LoRa.

3. Typical application in distribution station area

3.1. Identification of station area topology

The topology identification is the business foundation of the distribution station area. The distribution station area is generally a tree structure, which is mostly divided into four levels, namely: low-voltage outgoing cabinet, branch box, distribution cabinet and meter box. The monitoring device and meter send the communication address and the voltage and current information collected by themselves to the intelligent distribution transformer terminal through wired or wireless way, so as to identify the topology of the station area [6].

3.1.1. Basic definition. It is stipulated that the initial address information of low-voltage outgoing cabinet, branch box, distribution cabinet and meter box monitoring device is 01 ~ 04 respectively. The intelligent transformation terminal according to the equipment parameter information sent by branch monitoring devices to determine the topology preliminarily.

| Table.1 The information of equipment on each layer |
|-----------------|----------------|-----------------|
| Level | Node | Device | Communication mode |
| 0 | Transformer | Intelligent terminal | / |
| 1 | Outgoing cabinet | Intelligent switch | RS485 |
| 2 | Branch box | Monitoring device | LoRa |
| 3 | Distribution cabinet | Monitoring device | LoRa |
| 4 | Meter box | Meter | HPLC |

3.1.2. Topology identification of each node. In the distribution station area, there are two characteristics of the upper and lower incoming/outgoing current: 1) the current at the inlet end of the same branch box is the sum of the currents at the outlet end, and it is the maximum; 2) the current value of the outgoing terminal and the incoming terminal of the next branch box must be equal. So, we can determine the topological position and connection of each node based on these characteristics. Taking the first/second level topology connection relationship identification as an example, the implementation process of the specific scheme is explained.
Step 1: Read the current information with the starting address of 01, find the maximum current value \( i_1 \), determine that the branch is the incoming terminal of the primary outgoing cabinet, mark the branch as B1, and write the equipment parameters, communication address and other information of the branch into the XML file.

Step 2: According to the magnitude of current, \( i_{11} \sim i_{1n} \) is marked as B1/1-B1/n, which is used as the line of B1 and written in XML file. For example, B1/2, indicates the 2# line of the outgoing cabinet.

Step 3: Read the current information with the starting address of 02, find the incoming terminal of the branch box according to the principle of maximum amplitude and equal incoming/outgoing current, mark the serial number and write it into the XML file. For example, it refers to branch box No.1 connected with outgoing line B1/2.

Step 4: According to the current amplitude, mark the outlet serial number of the branch box and write it into the XML file.

The other node identification methods are the same as above, and the intelligent distribution transformer terminal completes the identification of the overall topology of the substation area.

3.1.3. Distribution area user-phase-transformer relationship identification. According to the voltage data of master meter and user meter, the correlation analysis of voltage data is carried out, and the transformer phase household identification is carried out.

The voltage correlation calculation methods include KNN, grey correlation analysis, etc. In this paper, Pearson method is used to calculate the voltage correlation [7]. Firstly, the intelligent terminal obtains the data \( U_{ai}, U_{bi}, U_{ci} \) of the master meter in each area and the data \( U_k \) of each user meter every 15 minutes within 24 hours. Then, the correlation between the user table and each phase of the general table of each station area is calculated according to equation (1).

\[
\rho_{x,y} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}
\]  \hspace{1cm} (1)

Here, \( \rho \) is the correlation coefficient, \( X_i \) is the voltage of each master meter at each time, \( \bar{X} \) is the average voltage of the master meter, \( Y_i \) is the voltage of each user meter at each time, \( \bar{Y} \) is the average voltage of each user meter.

The correlation between variables X and Y is:

1) If \( |\rho_{x,y}| \geq 0.8 \), there is a highly correlation between X and Y.

2) If \( 0.8 > |\rho_{x,y}| \geq 0.5 \), there is a general correlation between X and Y, we need to reconfirm.

3) If \( |\rho_{x,y}| < 0.5 \), there is no correlation between X and Y.

If the correlation coefficient between a user meter and one phase of a master meter (such as phase-A) is the largest, it is considered that the user meter is connected with master single-phase meter. Referring to the numbering method of the branch serial number mentioned above, the description is
different after the serial number of the station area master table, which is written into the XML file as the information of the user table. Finally, the intelligent distribution terminal sends the XML file recording the topology information to the distribution master station for operation and maintenance.

3.2. Line impedance analysis

Combined with the application of smart meter and power consumption information acquisition technology, the intelligent terminal in substation area can obtain power consumption data information, and analyse the impedance of low-voltage distribution line in substation area, study and judge the aging of low-voltage distribution line, reduce system faults, and identify suspected power stealing.

By collecting the real-time and historical operation data of terminal monitoring unit and branch node monitoring unit, the intelligent distribution transformer terminal calculates the impedance of each low-voltage node in the substation area (Fig.3).

In the simplified system model of distribution station area (Fig.4), for a single-phase user, when the power supply voltage is constant and the impedance changes, the impedance of this section of line is as follows:

$$Z = \frac{\Delta V}{\Delta I} = \frac{V_{ob} - V_{on}}{I_{ob} - I_{on}}$$

$$= \frac{(R_d + R_c) \times (I_{ob} - I_{on})}{I_{ob} - I_{on}} + R_d + R_m$$

(2)

Calculate the impedance of each client. For normal low-voltage distribution lines, the impedance value is about 0.039Ω/100 m, and no more than 0.2Ω.
1) If the calculated impedance of a distribution line is greater than 0.2Ω, it indicates that the line is aging.

2) If the impedance value of a certain distribution line suddenly increases, it means that the user's meter may be short circuited, resulting in the flow of electricity through the meter under normal circumstances, so it can be considered that the user is suspected of stealing electricity.

3.3. Three phase unbalanced treatment

The intelligent commutation switch equipment is deployed at the front of single-phase users in substation area. The intelligent distribution transformer terminal collects the current and voltage information of each intelligent commutation switch through 4G and other communication methods. Combined with the three-phase total load current and voltage at the outlet of distribution transformer, the unbalance degree is identified and the commutation switch is switched.

\[
I_{av} = \frac{(I_a + I_b + I_c)}{3}
\]

\[
\beta_a = \frac{|I_a - I_{av}|}{I_{av}} \times 100\%
\]

\[
I_a = I_a - I_{av}
\]

The total load current of each phase in intelligent distribution transformer terminal acquisition area is \(I_a, I_b, I_c\). The current at the intelligent switch is \(I_{a1}, I_{b1}, I_{c1}\). Refer to equation (3) to calculate the average current of three-phase load, and take phase-A as an example, refer to equation (4)&(5) to calculate the unbalance degree of each phase and the non-transferable load respectively [8].

In order to ensure the service life of the intelligent commutation switch, the minimum commutation times is generally used as the control strategy.

Firstly, according to the current phase of each commutation switch, the original state table of three-phase load is formed, in which the identification, phase information and load of commutation switch are recorded. Then, judge the positive/negative situation of \(I_a, I_b, I_c\), and determine the load transfer out/in. The positive value represents the transfer out load and the negative value represents the transfer in load.

1) The current A-phase load is sorted according to the amplitude, and the corresponding commutation switch of each load is marked.

2) Starting from the maximum load \(I_a\), if the load is within the load range of B/C phase to be transferred, the three-phase load value after the load is transferred to B/C phase is predicted, and the three-phase unbalance degree is calculated.

3) Comparing the three-phase unbalance, if the three-phase unbalance is reduced, the commutation switch is added to the B/C phase execution queue.

4) Continue to judge the next load according to the same method until the unbalance degree of each phase is less than the setting of \(I_{umb}\).

5) According to the execution queue of each switch, the commutation switch operation to be executed is controlled.

The transfer of two-phase load to one phase is similar to the above method, which finally makes the three-phase unbalance reach the setting range and completes the unbalance adjustment.

3.4. Other business

In addition to the above typical applications, under the overall framework of intelligent substation area, intelligent distribution transformer terminal can also carry out many business functions, such as low-voltage fault diagnosis, low-voltage power load sensing, intelligent monitoring of distribution transformer operation, substation area load forecasting, orderly charging control of electric vehicles, etc., so as to improve the management level of substation area on the basis of comprehensive perception of substation area.
4. Engineering implementation
Taking the new intelligent distribution transformer terminal as the carrier, we develop the app software of the functional module for the typical business scheme designed in this paper. State Grid HeNan Electric Power Company has applied the intelligent distribution transformation terminal and business scheme in several stations with high reliability and service level in Zhengzhou. The main achievements are as follows:
1) The monitoring of the operation status of the station area is realized. Collect the operation data of the incoming and outgoing lines, master the voltage and current data of the low-voltage line in real time, and complete the monitoring of the on/off status, residual current value and alarm information of the low-voltage switch.
2) Realize the operation status diagnosis and control of the station area. Intelligent diagnosis and location of equipment light and heavy load, low voltage, three-phase imbalance and other problems.
3) Provide data display in the station area. Provide topology data of distribution network such as line transformer relationship, station household relationship and operation data such as power failure abnormal events, and provide visualization display services such as topology path and power failure range.

In the future, according to the technical route of distribution Internet of things, we will strengthen the research on the local decision-making of intelligent distribution and transformation terminal and distribution automation master station system and the "cloud-side" collaborative management mechanism, so as to support the construction of convenient operation and maintenance service capacity of low-voltage distribution network.

5. Conclusion
Under the development trend of intelligent distribution area and Internet of things, we take intelligent distribution transformer terminal as the center, and construct intelligent distribution area system based on the access of intelligent acquisition and sensing equipment. Combined with the concept of edge computing, it studies and designs typical business schemes such as station topology identification, line impedance analysis, three-phase imbalance treatment. The effect is remarkable, which can provide support for the construction of intelligent distribution area. After the promotion of the scheme, it can not only effectively process and utilize the data of the station area, but also help to improve the operation and maintenance, and improve the lean management level of the distribution station area.

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References
[1] LIU Riliang, LIU Haitao, XIA Shengfeng, et al. Internet of Things technology application and prospects in distribution transformer service area management[J]. High Voltage Engineering, 2019, 45(6):1707-1714.
[2] LÜ Jun, LUAN Wenpeng, LIU Riliang, et al. Architecture of distribution internet of things based on widespread sensing&software defined technology[J]. Power System Technology, 2018, 42(10): 3110-3117.
[3] ZHANG Jichuan, CHEN Lei, ZHANG Mingyu, WANG Peng, FANG Mu, SUN Haoyang, et al. Conception and Application of Smart Terminal for Distribution Internet of Things[J]. High Voltage Engineering, 2019, 45(06): 1729-1736
[4] WANG Li, WANG Jinli, JIANG Fuxiu. A new mode for intelligent power distribution area[J]. Rural Electrification, 2016(9): 17-19.
[5] LIANG Zhixian, WANG Jian, GU Mingying. Research and application on power distribution communications technology for smart grid[J]. Telecommunications for Electric Power System, 2012, 33(3): 75-79.
[6] XIAO Yong, ZHAO Yun, TU Zhidong, et al. Topology checking method for low voltage distribution network based on improved Pearson correlation coefficient. Power System Protection and Control, 2019, 47 (11):37-43.

[7] WU Bingxin, LI Jungang, CUI Longwei, et al. Study of distribution area user-phase-transformer relationship and primary topology identification[J]. Distribution & Utilization, 2020, 37(11):1-7, 27.

[8] Zhu Mingxing, Li Kaijin. Calculation method and application of three-phase unbalance in low voltage distribution network[J]. Electrical Measurement & Instrumentation, 2019, 56(2): 41-46.