Design of Intelligent IoT Sensing Module Based on Topology Recognition

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Abstract. With the development of the Power IoT (Internet of Things), the traditional terminal collection devices are not able to meet the huge and accurate data collection demands. In order to complete the requirements of comprehensive data collection and monitoring, line loss analysis and judgment, anti-theft, active repair and intelligent IoT access of other access devices, this paper puts forward intelligent management and control function of the smart sensing module. The new modular acquisition device takes miniaturization, modularization and integration as the design concept, takes the Internet of Things technology as the core, further strengthens the depth and breadth of low-voltage perception, assists the ubiquitous power Internet of Things construction. This paper mainly analyzes and discusses the hardware design, key technology and function realization of the intelligent IoT sensing module based on the Internet of Things.

1. Introduction

The low-voltage distribution network, located at the end of the whole power grid, is characterized by wide distribution, complex power supply and consumption environment, and difficult operation and maintenance. For a long time, there has been a lack of intelligent and efficient operation monitoring, operation and maintenance management means. For example: for users stealing electricity, it is impossible to monitor, analyze and early warning in real time, and can only rely on manual inspections and a small amount of monitoring data, which is extremely difficult to conceal and locate the point of investigation\cite{1}. For the "stubborn" high-loss stations, it is difficult to track the line loss electric quantity, so it cannot be calculated by classification to locate the anomaly reliably \cite{2}. The failure to realize automatic identification and real-time update of the topological relationship of the station area brings great inconvenience to the operation and maintenance, rush repair and other work, and brings a series of problems to the active rush repair positioning, power supply service optimization and other high-quality service work.

This paper mainly studies the intelligent IoT sensing module based on topology recognition. The new modular acquisition device integrates multiple technologies such as IoT sensing, topology recognition, edge calculation and video monitoring to monitor the power grid data and the weak links on the distribution side.
2. Technical architecture of intelligent IoT sensing module

2.1. Technology architecture of low-voltage station IoT sensing system

The technical architecture of the IoT sensing system in the low-voltage power distribution area is shown in Figure 1. The station controller is installed at the outlet switch of the transformer in the low-voltage distribution station, and the intelligent IoT sensing module is installed in the main switch of the distribution outlet line, each branch switch and the table box [3]. The platform controller communicates with the master station through 4G communication mode, and communicates with the intelligent IoT sensing module at all levels through HPLC high-speed carrier communication mode. Intelligent IoT sensing module is installed at each outlet switch of the branch box; Intelligent IoT sensing module is installed at the metering box, which communicates with the electricity meters in the meter box through RS485.

![Figure 1. Technology architecture of low-voltage power distribution station IoT sensing system](image)

2.2. Hardware design of intelligent IoT sensing module

The intelligent IoT sensing module adopts the guide rail type installation, and the overall hardware adopts the pluggable modular design. It is divided into three freely collocation units. The basic unit is the sensing module, the expandable unit control module and the protective module.

![Figure 2. Hardware design of intelligent IoT sensing module](image)

The sensing module is a management unit which integrates high frequency CPU, metering chip, HPLC communication chip, security encryption chip and platform identification module. The sensing module...
is transmitted with the station controller through HPLC communication and transmitted with the smart meter reading through the RS-485, supporting the DL/T645, DL/T698. The sensing module is equipped with low-power Bluetooth module, which supports short-range wireless and local maintenance and upgrade. And it has the ability to collect full electrical parameters, the built-in topology recognition module to realize automatic generation of the station topology, the built-in high-precision temperature and humidity sensors to monitor the environmental status in the box in real time. The State Grid security chip is loaded to ensure the security and integrity of data [4].

The control module has a built-in Beidou positioning module, combined with the sensing module to automatically report fault events to realize the optimal path and real-time map navigation formulated by the repair personnel; the acceleration sensor can realize the tilt detection, vibration detection, movement detection and other functions of the cabinet; The lock control module has intelligent lock management and control functions, supports remote unlocking and local Bluetooth authentication unlocking, and real-time feedback of the door lock switch status [5].

The protection module has a built-in pyroelectric infrared body detection sensor, strong magnetic induction module, evidence camera device and SD card storage, which can detect whether there is a person operating in front of the device and linkage with the locking state of the smart box. When there is an illegal invasion, the protection module triggers the camera device to take continuous photos, store them to the local retention card, and upload them to the main station through the perception module to trigger the early warning. It can also monitor illegal unpacking, stealing electric power and other abnormal behaviors in real time according to the measurement accuracy of strong magnetic interference.

3. Relevant analysis of Topology Recognition

3.1. Characteristic current communication technology

Install the intelligent IoT sensing terminal at the key position of the line, and generate a characteristic current signal that meets certain frequency domain rules by switching resistance between the line zero and the live line [6]. The intelligent IoT sensing terminal and platform controller conduct real-time sampling and analysis on the line current signal, record the time mark recognized by the signal, make comparative analysis on the time mark, and draw the physical topology of the line.

3.1.1. Signal transmission

With 833.3Hz on-off switch (1.2ms as a cycle, 400μs on, 800μs off), the circuit will generate current signals offset by 833.3Hz plus or minus 50Hz. The peak value of the current signal is 420mA (at 220V voltage), and the current signals of 783.3Hz and 883.3Hz are generated on the circuit [7]. The topology identification can be carried out by detecting the presence or absence of these two signals. The 16-bit binary code is 1 0 1 0 1 0 1 1 0 1 0 0 1. Where, no characteristic current is sent when code point is 0, and characteristic current is sent when code point is 1. Figures 3 and 4 are the corresponding schematic diagrams.

![Figure 3. Figure of characteristic current code levels.](image1)

![Figure 4. Characteristic current waveform.](image2)
The single transmission time is 9.6s, that is, the length of each encoding transmission time is 0.6s. The total time deviation of a single transmission is ±40ms, and the allowable time deviation of each code is ±15ms.

3.1.2. Signal identification

The sliding DFT is used to extract the current signal on the line in real time, and the amplitude of 783Hz and 883Hz frequency domain components is calculated [8]. The sum of the two is used as the judgment standard for decoding. After algorithm processing, the waveform is shown in Figure 5.

![Decoded waveform](image)

**Figure 5.** Decoded waveform.

By decoding and analyzing the three-phase current and comparing the magnitude of the amplitude, the household transformation relationship and phase attribution of the electricity meter are determined. When the three-phase real-time detection is conducted, the strongest phase of the characteristic current signal is identified as the phase of the electricity meter.

3.2. Topology identification process

The first step is to identify patterns in parallel. All areas are identified at the same time. The master station selects the platform area for topology identification, and sets the start time of device transmission X and the transmission interval L to start the parallel mode of topology identification [9]. The master station automatically combs the number of devices in the selected platform, M, and automatically sets the characteristic current transmission time of all devices at an interval of L starting from time point X, X, X+L, X+2L, ... , X + (M - 1) * L. All devices send characteristic current in turn at a preset time. If the station controller and the intelligent IOT sensing module detect the characteristic current signal, the current size, phase and recognition time will be stored in the local device, and the recognition result will be reported to the master station through the terminal.

The second step is to recognize the pattern serially. The devices screened out by parallel mode which are caused by time mark setting failure, communication failure, cross-platform interference and other reasons of missing recognition are identified one by one. For the devices that failed to be identified in the previous step, the master station sets the household transformer identification queue for the devices selected in accordance with interval K starting from time point Y, and informs the devices with corresponding addresses of the characteristic current transmission time through the terminal, and the devices switch current in turn. If the station controller and the intelligent IOT sensing module detect the characteristic current signal, the current size, phase and recognition time will be stored in the local device, and the recognition result will be reported to the master station through the terminal. The master station analyzes the storage records obtained from parallel mode and serial mode, and obtains the current user-transformer relationship and physical topology according to the time scale comparison algorithm.

4. Field application

In 2020, 140 intelligent IoT sensing modules have been piloted in 5 stations in Yantai and Dezhou of Shandong Province, and have achieved good results in operation and distribution data combing, station line loss management, active emergency repair, intelligent load regulation and other aspects. The relationship between users and electricity meters in the station area can be accurately identified, and the running status of electricity meters and metering boxes can be monitored online in real time. After the pilot implementation, line loss decreased from 10% to 1%-4%, which improved the power
Selected identification range
Set the start time and send interval, calculate the time queue
Turn on parallel mode
Calculate the time queue and generate the sending time
Sending device timescale setting
Time set successfully?
All devices are set up?
Y
N
Send characteristic current
Identify characteristic current and record time scale
More than 5 minutes?
Report identification results
All equipment report completed?
N
Y
Time scale analysis, get the results of household transformer and topology
Record the address and number of failed identification

Is there a failed device?
Y
Turns on serial mode
Calculate the time queue and generate the sending time
Sending device timescale setting
Time set successfully?
All devices are set up?
N
Y
Send characteristic current on time
Identify characteristic current and record time scale
More than 5 minutes?
Report identification results
All equipment report completed?
N
Y
Time scale analysis, get the results of household transformer and topology
The end

Figure 6. Topology identification process.

Figure 7. Field installation and operation figure of intelligent IoT sensing module.
supply capacity of the client side, effectively improved the measurement environment, and provided strong technical support for line loss management. By combining the topological relationship of the low-voltage distribution network, the real-time situation of shutdown and return of power with the grid GIS, the fault location can be quickly located and the emergency repair force can be reasonably arranged, so that the repair service can be changed from passive to active, and the power outage time of customers can be effectively shortened.

5. Summary
In this paper, an intelligent IoT sensing module based on topology recognition is designed, which mainly uses technologies such as the Internet of Things, sensor measurement, and edge computing to enhance the depth and breadth of low-voltage terminal sensing. This design focuses on the dimensions of extensive interconnection, panoramic perception, active service, and value extension, strives to improve the quality of power supply service capabilities and the lean management capabilities of enterprises, gives full play to the platform and resource advantages of power supply companies, and use energy data to serve the development of people’s livelihoods. It realizes the comprehensive perception, rapid response and intelligent decision-making of 400V low-voltage power distribution system.

6. References
[1] Shang Song, Chai Yuhua, Sun Ying. The Harmonic Detection Based on Wavelet Transform and the Fast Fourier Transform[J]. Electrical Measurement & Instrumentation, 2012, 49(7): 29 -32.
[2] Zhu Zili, Ye Faxing. Improved Method for Theoretical Line Loss Calculation of Low - Voltage Distribution Network[J]. Electrical Measurement & Instrumentation, 2012, 49(11): 6 -10, 70.
[3] Cui Xiaorong , Wang Jun, Cao Ling, et al. Current Status and Development Trend of Power System Harmonic Detection Method[J]. Electrical Measurement & Instrumentation, 2012, 49(5): 6-10, 16.
[4] Osman A H, Hassan M S, Sulaiman M. Communication-based Adaptive Protection for Distribution Systems Penetrated with Distributed Generators. Electric Power Components and Systems, 2015, 43(5): 556-565.
[5] Gupta R, Baby A, Arya P V, et al. Upgrading Reliability of Water Distribution Networks Recognizing Valve Locations. Procedia Engineering, 2014, 89: 370-377.
[6] Majumder R, Ghosh A, Ledwich G, et al. Load sharing and power quality enhanced operation of a distributed microgrid. Renewable Power Generation, IET, 2009, 3(2):109-119.
[7] Sfikas E E, Katsigiannis Y A, Georgilakis P S. Simultaneous capacity optimization of distributed generation and storage in medium voltage microgrids. International Journal of Electrical Power & Energy Systems, 2015, 67: 101-113.
[8] Shang Song, Chai Yuhua, Sun Ying. The Harmonic Detection Based on Wavelet Transform and the Fast Fourier Transform[J]. Electrical Measurement & Instrumentation, 2012, 49(7): 29 -32.
[9] Samet H, Khorasany M. Protection of Ring Distribution Networks with Distributed Generation Based on Petri Nets. Sustainability in Energy and Buildings. Springer Berlin Heidelberg.

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