Topology Identification Method of Urban Power Grid Based on 5G Communication

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Abstract: With the development of 5G communication technology and intelligent terminal technology of urban power grid, intelligent distributed control mode independent of master station will become the trend of intelligent distribution network in the future. The characteristics of flexible configuration and strong scalability make 5G communication technology provide a wireless solution, which greatly gets rid of the constraints of communication cables and promotes the popularization and application of intelligent distributed control technology. Based on 5G communication technology, this paper proposes a distributed topology identification method. In this solution, each Smart Terminal Unit (STU) only needs to configure its associated static network topology information, and each STU forms dynamic network topology information according to certain topology identification rules. The purpose of identifying topological information is to use the information to provide topological information support for advanced functions of the distribution network, such as reclosing, identification of distributed power islands, and restoration of non-faulty section power supply.

1. Introduction
At present, the distributed generation (DG) is mostly directly connected to the high-voltage power grid. To further improve the local absorption capacity of distributed power supply, more and more distributed generation begin to access the middle and low voltage distribution network, which makes the traditional single-terminal passive distribution network evolve into multi-terminal and multi-source active distribution network. A large quantity of access of DG brings great difficulties to the self-healing control of the existing distribution network [1].

From the perspective of fault location and fault isolation, the power flow in an active distribution network flows in multiple directions. When a fault occurs, the upstream and downstream sections of the fault point may flow through the fault current and thus the original fault section location method is no longer applicable [2]. From the perspective of fault recovery, distributed power supply brings both opportunities and challenges. Active distribution network contains multiple power sources. If DG can be used to participate in power supply recovery, it is expected to greatly reduce the load loss rate and reduce the outage time of users. However, DG and system power supply need to cooperate with each other in the process of fault recovery, which undoubtedly increases the complexity of fault recovery [3].

The realization of self-healing function of distribution network depends on the corresponding control method. Most of the traditional control methods of distribution network are local control mode
and centralized control mode [4]. These methods not only limit the wide access of distributed power supply, but also have disadvantages such as slow processing speed and inflexible control methods. With the development of communication and smart terminals technology in distribution networks, the distributed and intelligent control mode independent of the master station becomes a trend of development smart distribution networks in the future.

The centralized mode has lower requirements on the distribution network terminal units, which only need to have measurement and communication functions, and do not need to realize scheme decision and switch action autonomously. If the distributed control mode is adopted, the distribution network terminal unit should shoulder the task of the original master station, which requires it to realize intelligence and become a smart terminal unit (STU). In general, STU needs to have the ability of data acquisition and processing, communication, information sharing, decision analysis and synergy.

At present, there are some examples in the power system to apply fibre optic communication to the distributed topology identification and fault recovery of distribution network. However, considering that there are many terminal devices in the protection configuration of urban power grid, many optical cables should be laid if differential protection is configured in the protection terminal of power grid line, which results in high investment cost and great difficulty in implementation. According to the characteristics of 5G communication with high bandwidth and low delay, 5G wireless communication can be applied in power grid protection and control [5]. Protection devices on both sides of power grid lines can establish peer-to-peer communication network through 5G communication, providing information interaction channels for realizing longitudinal differential protection and fault recovery function of distribution network.

The 5G communication technology has great flexibility and adaptability, hence DG can conveniently access to the protection and control system of existing distribution network. Mobile edge computing (MEC) technology based on 5g communication extends the cloud computing infrastructure to the network edge, making the cloud computing centre closer to the user side. By localizing and marginalizing communication, storage, and computing resources, the ability to accelerate content acquisition, application deployment, and provide services close to users in wireless networks can be achieved, thereby reducing user access delays and device power consumption. Network slicing is an important enabling technology for 5g mobile communication network. Based on MEC technology, network slicing will take on the form of "one logical architecture and multiple networking architectures". In other words, 5g network physical infrastructure resources are virtualized into multiple independent parallel network slices, each of which serves a specific business scenario to meet the differentiated requirements of different business scenarios on bandwidth, delay, service quality, etc. Unlike the one size fits all 4G core networks, the 5G core network must be flexible and adaptable and is expected to simultaneously provide optimized support for the diverse 5G use case categories [6]. Compared with previous generations of mobile communication technologies, 5G+ network slicing technology enables wireless cellular networks to theoretically have the possibility of being applied to the core industrial control services of the power grid for the first time.

2. Establishment of peer to peer communication network based on 5g communication

The control plane (CP) and user plane (UP) of traditional core network equipment are not completely separated, so core network equipment can only be placed in provincial capital cities. The traffic first converges to the provincial capital core network, and then enters the Internet cloud for processing. There is a long spatial distance between users and cloud applications. This distance may even exceed 500 kilometres. IP packets will pass through many routing nodes and optical fibre transmission equipment, which will cause a large delay. In response to the low latency and high bandwidth requirements of 5G, 3GPP and ETSI have designed MEC (Multi-access Edge Computing) solutions.
As shown in Figure 1, the MEC system deploys user plane equipment UPF to network edge nodes, shortens the transmission distance between UE and UPF and reduces the number of route hops, thereby reducing latency, which not only meets the expansion requirements of terminal equipment computing capabilities, but also makes up for the long delay of cloud computing.

The steps to build a peer-to-peer communication network based on MEC are as follows:

1. Insert a qualified telecommunications operator’s dedicated SIM card into a 5G wireless terminal to receive 5G signals and implement routing functions. Within the signal coverage of 5G base stations, access the 5G network slicing private network customized by the network operator. The IP address obtained by the 5G SIM card from the network operator is fixed and long-term online. Different 5G SIM cards can send and receive data based on the TCP/IP protocol.

2. The 5G wireless terminal device is configured so that the data of the digital protection device connected to the 5G signal receiving module of the opposite end can be forwarded to the digital protection device at the local end, so as to realize the mutual interaction of the data of the two digital protection devices.

### 3. Identification and storage of network topology information

Topology information is generally divided into static topology information and dynamic topology information.

| Categories        | Name                                      |
|-------------------|-------------------------------------------|
| STU Basic information | The STU number, IP                        |
|                   | Adjacent STU1 number, IP                  |
|                   | Adjacent STU2 number, IP                  |
|                   | ...                                       |
|                   | Adjacent STUnumber, IP                    |
Static network topology information mainly includes two parts, STU basic information such as number, communication address, etc. and bus adjacent section information represented by switch sets. These information needs to be manually configured by the staff, and generally does not change when the network structure does not change. Each STU only configures the relevant information of the STU and its neighbouring STUs, so the system configuration and maintenance is very difficult. During the initial configuration, the static network topology information stored in each STU is shown in Table 1.

In the case that the grid structure of the distribution system remains unchanged, the change of the network operation mode will cause the change of the topology structure, and then the topology information will change. This scheme mainly introduces the "hand in hand" distribution network with a relatively simple topology. After being put into operation, STU takes the initiative to obtain the corresponding topology information. In the subsequent operation process, the topology information should be automatically updated after the operation mode changes to adapt to the changes in the operation status.

The rules of topology information identification are as follows:

1. Taking the start of the STU on the power supply side as the starting point for identification, the STU first sends a "switch status query command" to its neighbouring STU to make it query the status of the switch it monitors.

2. When the STU receives a switch status query command from an adjacent STU.
   a) Mark that the STU sending instructions to itself is the upstream STU, and the other adjacent STUs are the downstream STUs; correspondingly, if the opposite STU of the section where the switch controlled by this STU is located is the upstream STU, the switch is the upstream switch, and the other switches are downstream switch.
   b) If all the switches controlled by the STU are in the closed state, the switch state query command will continue to be forwarded to the downstream STU; if a certain STU monitors that there is a switch in the open state or no more adjacent STUs, it will stop forwarding messages.

3. When a certain STU receives query, instructions forwarded from different adjacent STUs, and one of the controlled switches is in the off state, it is determined that it is the STU at the contact switch. After the STU at the contact switch confirms its own attributes, it forwards its own communication address to all its neighbouring STUs, and each STU relays the information after receiving the information to the power-side STU.

Following the above information query and forwarding process, each STU can form a dynamic network topology information table as shown in Table 2.

| Categories | List of adjacent STUs | Relationship |
|------------|-----------------------|--------------|
| STU        | STU1                  | Upstream/Downstream |
|            | STU2                  | Upstream/Downstream |
|            | ...                   | Upstream/Downstream |
|            | STU n                 | Upstream/Downstream |
| Breaker    | Upstream              | Downstream    |
| Tie Breaker| STU’s IP at the Tie Breaker |

Table 2. Topology information of dynamic network in STU
4. Application examples of topology information

4.1. Topological information applied to island detection
When a section is isolated due to a fault, the STU located downstream of the faulty section forwards the switch off information to its downstream STU. After receiving the message, each STU continues to forward it downstream until the STU at the tie switch. In this process, if the STU at the PCC of the DG receives a message that a switch downstream of the faulty section is disconnected or the STU at the PCC is the STU downstream of the faulty section, the DG can determine that it is in an island state. As shown in Fig. 3, a fault occurs at point F1. Firstly, fault information is exchanged between STU1 and STU2 via 5G CPE. Secondly, K12 and K21 are disconnected to isolate the fault. Thirdly, STU2 forwards the fault information to the downstream STU3. Finally, STU3 determines that the DG connected to itself is in the state of island operation.

![Figure 3. Islanding detection process.](image)

4.2. Reclosing and non-fault section power supply restoration scheme
In the process of the upstream STU forwarding the query command to the downstream STU, the STU can identify the distance between itself and the power supply. After a topology identification, the topology information can be applied to the reclosing strategy of the distribution network that the near power source side is closed first, and if the near power source side is successfully closed, the remote power source side is closed again.

After the fault section is removed, the upstream STU of the section starts to reclose the corresponding switch after a delay. If the fault is permanent, the upstream STU detects secondary overcurrent and trips the breaker on the local side; if the fault is transient, the upstream STU sends a successful reclosing message to the downstream STU. After receiving the message, the downstream STU sends a closing command to the downstream switch of the section to complete the entire reclosing process. If it is a permanent fault, in addition to issuing a trip command, the upstream STU will also send a closing command to the STU at the tie switch. The STU at the tie switch will close the circuit breaker when the conditions are met to realize the restoration of power supply in the non-faulty section.

![Figure 4. Active distribution network equipped with STUs.](image)
Taking the ring network shown in Fig. 3 as an example, it is assumed that F1 is a transient fault and F2 is a permanent fault.

1) When a fault occurs at F1, after the faulty section is isolated, STU1 on the side of the power source first orders K12 to reclose. Since F1 is a transient fault, K12 recloses successfully. Stu2 orders K21 to close after receiving a message from Stu1 that reclosing has been successful.

2) When a fault occurs at F2, after the faulted section is isolated, STU6 on the side of the power source first orders K62 to reclose. Since F2 is a permanent fault, K62 reclose fails. In addition to sending a trip command to K62, STU6 will also send a closing command to STU4 at the tie switch. After receiving the message, STU4 orders K42 to close, thereby completing the power supply of the non-faulty section.

5. Conclusion
This paper proposes an intelligent distributed distribution network topology identification and application method based on 5G communication, which has the following characteristics:

1) There is less information that needs to be manually configured. It is only necessary to configure static network topology information related to its own location for each STU. The dynamic network topology information is obtained through topology recognition, and manual configuration is not required.

2) This solution disperses local topology information in each STU, and requires low storage and computing capabilities for each STU. It can provide fast topology information support for advanced functions of the distribution network, which is conducive to rapid island detection and fast power supply restoration in non-faulty areas.

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