

# 地铁 35 kV 环网数字通信电流保护测试方法

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**摘 要** 35 kV 中压环网供电系统是地铁的大动脉, 为地铁车辆及车站动力照明提供了可靠的动力来源。随着各大城市地铁线网规划的日渐加密, 线网共享主变电所、中压环网大分区供电等更加经济性的供电方式已普遍应用, 同时也使数字通信电流保护因其保护方法广泛的适应性和完备性也随之得以推广。在介绍数字通信电流保护实现原理的基础上, 采用添加定时模块的新型继电保护测试仪, 进行了多站同步加量测试。阐述了环网正常供电及故障运行方式下站间环网故障、母线故障、馈线故障等典型故障的实际测试方法及其逻辑判断分析。可为新建地铁线路数字通信电流保护功能的完整校验提供参考建议。

**关键词** 地铁; 供电; 数字通信; 电流保护; 测试方案

**中图分类号** U223.8<sup>2</sup>

**DOI:**10.16037/j.1007-869x.2019.06.043

## Protection and Testing Method of Digital Communication Current in Metro 35 kV Loop Network

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**Abstract** 35 kV loop network power supply system is the main artery of metro, it provides reliable source of power for metro station and lighting. With the expansion of metro planning in most big Chinese cities, more economic power supply systems such as the wire-net shared main substation and the large partition power supply for medium loop network have been widely adopted, and digital current protection is greatly promoted by the wide adaptability and completeness of the protection scheme. With an introduction of the implementation principle of digital current protection, the new relay protection tester with timing modular is applied to the multiple-station synchronous accelerometer test, the measuring method and logical judgment of the typical faults under normal loop network power supply and fault operation mode are elaborated respectively. This research provides a reference for the complete verification of digital communication current protection on newly built lines.

**Key words** metro; power supply; digital communication; current protection; testing scheme

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地铁 35 kV 中压环网数字通信电流保护能适应多级串行供电系统, 具有“绝对选择性”, 解决了传统保护的级差配合难题, 适应地铁实际运行环境, 可有效实现地铁中压环网大分区供电。其在供电方式调整时能自动适应“正常供电”和“支援供电”两种运行方式, 保护定值不再需要进行调整, 为地铁线路快速恢复供电提供了有力保障。此外, 数字通信电流保护的优越性也对校验保护方案的完整性提出了更高的要求。如何对新建线路中压环网数字通信电流保护进行全面测试校验, 为地铁开通运营保驾护航, 是研究此项技术现场应用的关键。

## 1 数字通信电流保护的实现原理

地铁交流供电系统采用环网供电方式, 每个变电所设置环网进出线开关柜, 并在进出线开关柜设置线网电缆及母线保护。如图 1 所示, 数字通信电流保护常用近区加速实现, 采用双差动保护形式, 即后备保护装置也兼具差动功能。站内进、出线柜后备保护装置用硬接线连接, 传递故障定位  $a$  信号; 站间差动保护及后备保护装置用光纤连接, 传递过流同步开放信号。正常运行过程中过流Ⅲ段永久运行, 过流Ⅰ段处于闭锁状态, 通过  $a$  信号判断是否开放过流Ⅰ段。在后备保护中, 定义内部故障定位信号  $a$ , 当本柜后备保护装置差动未启动且检测到大电流时定义  $a=1$ , 反之  $a=0$ 。本柜  $a=1$  且对侧后备装置  $a=0$  时解锁本柜过流Ⅰ段。同时通过后备光纤通道将过流开放信息发送至对端开关柜, 开放对端后备装置过流Ⅰ段, 成为下级站开关失灵的后备保护。所内馈线及母联保护装置不参与数字通信, 通过常规时间级差实现保护选择性, 动态级差确保不越级动作。当供电方向发生改变时, 进、出线柜功能互换, 保护功能不变, 故障定位信号自动与之匹配, 锁定故障范围。

## 2 测试技术

传统的继电保护测试仪主要应用于供电系统中

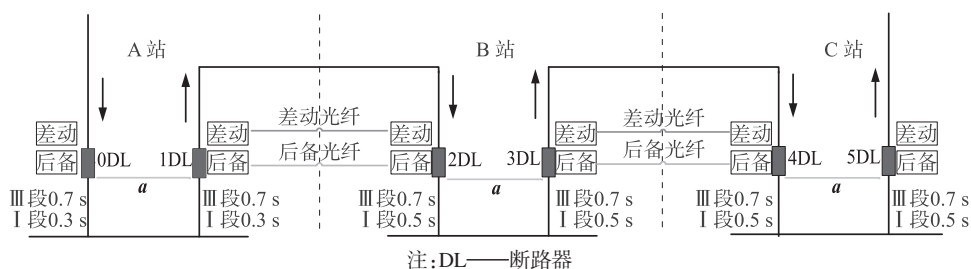


图1 环网进出线开关柜保护配置图

单体设备单装置保护功能的精准校验,在电力系统及地铁供电系统应用极为广泛。目前国内主流品牌的继电保护测试仪售价为15万~20万元不等。随着数字通信电流保护技术在地铁环网供电系统的广泛应用,其保护实现原理决定了保护校验的特殊性,而传统的继电保护测试仪无法实现多台设备联机同步输出功能,不能对数字通信电流保护进行全面的测试校验。

由于数字通信电流保护的选择性涉及多个变电所逻辑的同步判断,任一环节出错将导致供电分区内出现越级跳闸,所以实现逻辑功能的完整校验是数字通信电流保护得以可靠应用的关键。考虑到地铁变电所所属地下环境以及保护方法的差异性,基于GPS(全球定位系统)、光纤B码等对时技术的多站同步输出测试仪,为数字通信电流保护校验提供了新的测试思路。新型的继电保护测试仪在传统测试仪的基础上集成配置了对时模块,仅增加约5 000~8 000元的费用,便可以实现多机同步输出功能;同时可充分利用地铁环网特有的站间差动预留光纤,实现继电保护测试仪多站同步信号发送接收,从而解决了环网供电系统站间同步联调的难题。

### 3 测试方法

多站同步加量测试可完全模拟实际运营期间的各类型环网故障点位,以单元化的测试思路,在多站保护装置进行故障逻辑同步判断,从而实现保护逻辑站内、站间的同步校验。

现场测试以地铁A、B、C三站同I(II)段母线为测试单元,A、B站放置同步加量测试仪器。利用站间预留的差动光纤实现模块时钟同步,通过设定统一输出时间实现继电保护测试仪同步加量。测试顺序以主变电所或开闭所电源出线为测试起点A站,测试主站为B站,逐站推进;每一座变电站均在测试过程中成为主站。

结合当前保护原理及测试方法,本文对典型故障实际测试方法及逻辑判断进行分析。

#### 3.1 BC站间环网故障

如图2所示,测试时,在A站103开关柜(以下简为103,余类同)加故障电流 $I$ ,时长0.4s,硬线开入模拟103收到站内101的 $a=1$ 信号;在B站101和103加故障电流 $I$ ,时长0.4s。

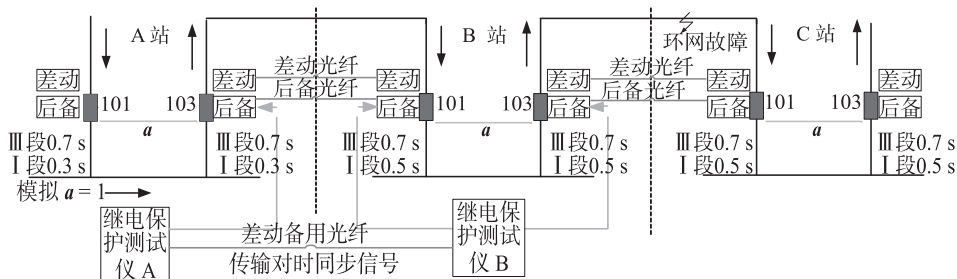


图2 区间环网故障示意图

观察分析B站103和C站101的差动装置、后备装置差动是否同时动作。B站103差动启动且有故障电流 $a=0$ ,B站101差动未启动且有故障电流 $a=1$ ,因此101开放过流I段,同时软件开放A站103过流I段。模拟A站103收到站内101发出的 $a=1$ 信

号,上级站接收到大电流且差动未启动的信息,即表明来电方向在A站。因测试加量时间0.4s,即可模拟B站103和C站101的差动装置、后备装置差动动作已将故障可靠切除。A站103和B站101过流I段保护出口延时未达到,保护立即返回。模拟B

站断路器失灵,测试方法同上,通过对调整加量时长至 0.6 s,模拟 B 站 103 切除故障失败,由后备保护 A 站 103 和 B 站 101 过流 I 段动作出口跳闸。

### 3.2 B 站母线故障

如图 3 所示,测试时在 A 站 103 加故障电流  $I$ ,时长 0.6 s,硬线开入模拟 103 收到站内 101 的  $a=1$  信

号;在 B 站 101 和 103 加故障电流  $I$ ,时长 0.6 s。

103 过流 I 段开放逻辑分析过程同 BC 环网故障。因测试加量时间 0.6 s,即模拟 A 站 103 和 B 站 101 过流 I 段动作出口跳闸。因 A 站 103 和 B 站 101 过流 I 段保护同步开放,当 B 站 101 断路器失灵后故障点仍可通过 A 站 103 予以可靠切除。

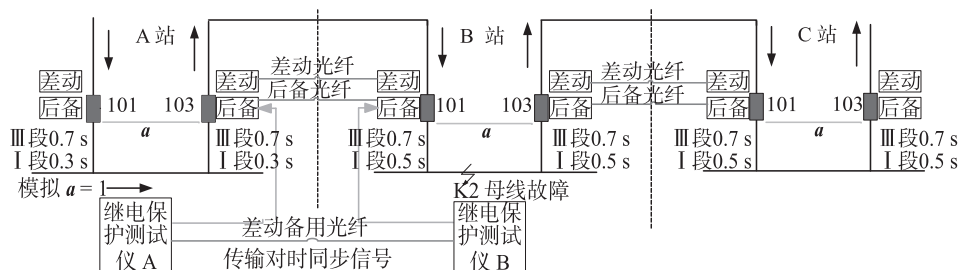


图3 站内母线故障示意图

### 3.3 B 站馈线故障

如图 4 所示,测试时在 A 站 103 加故障电流  $I$ ,时长 0.25 s,硬线开入模拟 103 收到站内 101 的  $a=1$  信号;在 B 站 101 和 111 加故障电流  $I$ ,时长 0.25 s。

B 站 101 和 A 站 103 过流 I 段开放逻辑分析同

BC 环网故障。因测试加量时间 0.25 s,即模拟 B 站 111 过流保护动作出口跳闸。因 A 站 103 和 B 站 101 过流 I 段保护同步开放,当 B 站 111 断路器失灵,故障点仍通过 A 站 103 和 B 站 101 同步可靠切除。

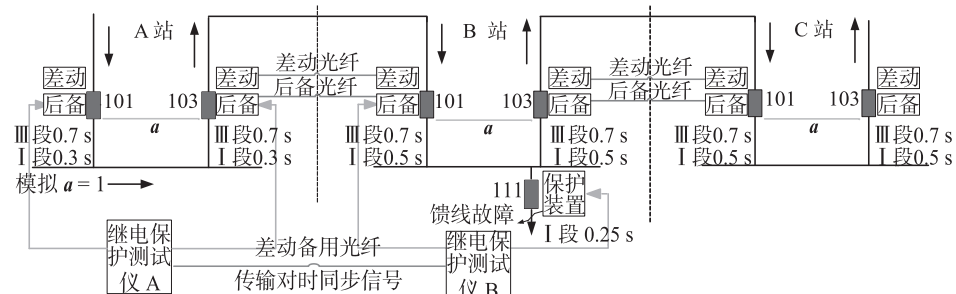


图4 站内馈线故障示意图

### 3.4 B 站 I 母支援 II 母供电, II 母故障

如图 5 所示,测试时在 A 站 103 加故障电流  $I$ ,时长 0.4 s,硬线开入模拟 103 收到站内 101 的  $a=1$  信号;在 B 站 101 和 110 加故障电流  $I$ ,时长 0.4 s。

B 站 101 和 A 站 103 过流 I 段开放逻辑测试分析同 BC 环网故障。因测试加量时间 0.4 s,即模拟 B 站 110 过流保护动作已将故障切除。A 站 103 和 B 站 101 过流 I 段动作延时未达到立即返回。模拟 B

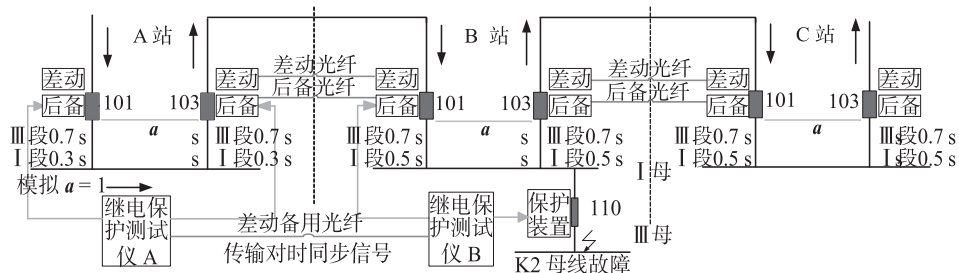


图5 站内 II 段母线故障示意图

站母联 110 断路器失灵,测试方法不变,通过对调整加量时长至 0.6 s,模拟 B 站母联 110 切除故障失败,由 A 站 103 和 B 站 101 过流 I 段动作出口跳闸。

#### 4 结语

供电系统是地铁新线建设的先头工程和重点工程。一旦环网带电,各专业调试将全面展开,再次大面积停电调试将严重影响其他专业的调试工作。因此,应充分把握环网保护调试时间,系统性地验证各保护动作的关键故障点。为使环网保护能得以成功应用,离不开与之匹配的测试方法,应充分发掘利用

新技术、新设备来打破传统的测试思路。多站同步加量测试技术在地铁供电系统的成功应用,从系统安全运行的角度来分析模拟故障点位的发生,通过全面性的功能验证,保证了地铁中压环网供电系统的可靠稳定运行,进而为地铁运营提供最有力的保障。

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(收稿日期:2017-08-21)

#### (Continued from Commentary)

aging and generating a lot of failures, which need to be overhauled and refurbished. When it comes to signaling, due to the limitations of system mode, i.e. track circuit or intermittent ATP, or the aging of the existing system, the demand of ever growing ridership can no longer be efficiently fulfilled.

The modernization of an existing line is more complex than building a new line and faces multiple challenges. For example, we have to ensure the operation of the existing line and take the new system into consideration to allow for interfaces. Technical solutions may vary as cities are different from each other in terms of network, ridership, and signaling system. Globally speaking, in UK where the world's earliest metro was built, the London 4 LM (Lines modernization) is the world's most complicated modernization project. In China, Shanghai Line 5 is the first urban rail line where operation, renovation, and construction were fulfilled at the same time.

The difficulty of resignaling resides in two aspects. Firstly, the new system replacing the old one should be as robust as the system for a new line. However, due to the constraints of the infrastructure of the existing line, many issues have to be tackled creatively. Secondly, resignaling cannot impact service or should at least keep the impact to the minimum. As there are many times of switchovers between the old and the new system, we have to ensure both safety and efficiency of commissioning. This makes it even more demanding for system development, site deployment, and construction planning. Take Shanghai Line 5 for example. The line was originally opened in 2003. The equipment was aging and the intermittent ATP system could no longer meet the requirement of ever increasing ridership. The resignaling of Shanghai Line 5 includes not only the replacement of the the signaling system but also adding 6-car trains to run in mixed operation with the existing 4-car trains, as well as the installation of platform screen doors and renovation of auxiliary tracks. In the meanwhile, the south extension was carried out. The resignaling should have no impact on the service of the existing line. TST's local innovation TSTCBTC®2.0 was selected for Shanghai Line 5. The system's dual CBTC architecture enhances the core functions of signaling and helps achieve higher availability. Less wayside equipment is required, which reduces the conflict of space for outdoor facilities and suits the reality of opening in different sections and in different time. With no service disruption, the cutover between the old and new signaling system was successfully completed in Oct, 2018 after more than 500 days of commissioning and over 1 000 switchovers. By the end of 2018, Shanghai Line 5 went into full line service.

The network of urban rail transport in China's mega cities and big cities is becoming more and more mature. We are expecting fewer new lines in the future, whilst modernization of existing lines will become the new normal. Besides Shanghai, Tianjin, Dalian, Chongqing, and Guangzhou either have lines modernized or are planning for it. For urban rail operators and system integrators, it is an all-time focus of safe and efficient operation. How to ensure continuous operation with a highly available system and how to upgrade the system through highly safe modernization with little risk are what we all need to think about. The resignaling and south extension of Shanghai Line 5 made many ground-breaking achievements, providing a lot of experience that can be shared to the industry. This also sets the stage for the standardization of urban rail modernization in China.