OPERATIONAL ANALYSIS AND IMPROVEMENT MEASURES FOR RESIDUAL CURRENT PROTECTION IN LV DISTRIBUTION

HUANG Chaoyi
Quanzhou Electric Power Supply Company
165480413@qq.com

LI Tianyou
Fujian Electricity Power Co.Ltd
2986010898@qq.com

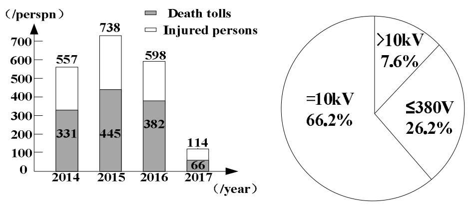
PAN Guomei
China Electric Power Research Institute
165480413@qq.com

ABSTRACT

According to official statistics of China, more than 85% of a death rate from electric shock occurs in LV distribution networks. In recent years, a lot of electric shock accidents caused by flood has been raising public awareness of the problems associated with the installation and operation of residual current devices (RCDs). This paper introduces the operational status and problems with residual current protection in LV distribution network, provides successful case studies in the reform process, and proposes measures for further improvement.

INTRODUCTION

Based on Statistics of China State Grid Business Area during the year of 2004 to the end of September 2017, there are total 2360 cases of personal electric shock injury disputes to occur where 531 cases are in the LV distribution network (26.2 percent).



a、Distribution of electric shock number b、Classification by voltage level
Fig.1 Analysis of electric shock damage on State Grid Business Area

The LV distribution network with a low voltage level involves many kinds of power devices and crisscrossed wires, and have various forms of electrical appliances and grounding mode. Therefore, the LV electric shock accidents (ESA) behaves high various and very complex. In recent years, the LV ESA also happened frequently at shower rooms, fountains, street lamps and the some like.

The standardizing grounding modes and rational configuration of residual current protective device (RCD) for LV ESA are much effective means to prevent persons from electric shock according to IEC and Chinese standards. The grounding modes in IEC regulations can be divided into TT system, TN system and IT system where TN system can also be divided into TN-C, TN-S and TN-C-S systems. At present, TT system and TN system are two main grounding modes in China. In addition, according to different grounding modes, there are corresponding classified fail-safe allocation principles[1] as shown in Table 1.

Tab.1 Grounding modes and graded protection

Protection & system	TT	TN-C	TN-S
Grade1 protection	√	×	√
Grade2 protection	√	√	√
Grade3 protection	√	√	√

However, the actual operations in some areas of China are not ideal. Fig. 2 shows the installation and operation of the first-class RCD in a coastal city in southern China which rate of putting into operation is only up to 22.67 percentage points. The main reasons for the low operation rate are the aging of line insulation, the zero-line common-use with the lines of other facilities, non-standard grounding mode, and un-installed user side RCDs.

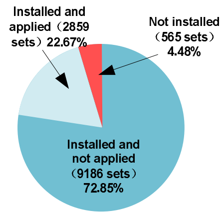


Fig.1 Installations and running of Grade1 protection

In summary, improving the reliability of low voltage shock protection is concerning to the grounding mode, leakage current detection and RCD degrees in different areas. This paper introduces the operational status and problems with residual current protection in LV distribution network, provides with successful case studies in the reform process, and proposes measures for further improvement.

1 SITUATION ANALYSIS & EXISTING PROBLEMS

1.1 The insulation aging

The insulation aging of distribution lines is really serious and the leakage current conducts into the earth through insulators, trees, and building walls. Especially in the plum rain season, leakage current is larger and can lead to RCD to frequently trip so that the protection has to be withdrawn so as to ensure the normal power supply to users.

1.2 Common zero line / zero line string

The LV power supply line and municipal streetlight are installed on the same pole, and the Zero Line of streetlight 'borrows' the Zero Line from power transformer on the same pole, commonly known as common zero line. When the streetlight is turned on at night, the RCD of the LV line detects the current flowing back from the phase line of the street lamp which leads to the wrong trip. In addition, the use of zero lines in different transformer areas, municipal lines (for communication, radio and television, etc.) or cross-zero within users is commonly known as zero line string. These two conditions can lead to leakage current exceeding the standard and result in Grade 1 protection tripping so that the staff has to withdraw the protection.

1.3 User internal irregular wiring

From the meter box lines to the user's internal lines, there are many problems, such as zero-line sharing and common use from different phase lines, or zero-line sharing and common use from different sources. Sometimes the current reaches 2 amperes and more which makes the Grade 2 protection be un-enable.

1.4 Grade 3 protection un-installation or un-putting into operation

Some user’s security awareness is weak. And their household protection Grade 3 is not installed or the protection is released by themselves due to large leakage current. The deteriorated insulation of the user line or the leakage current of the household equipment will cause Grade 1 or Grade 1 protection to mis-acting.

1.5 The lightning outage

Lightning strikes cause the RCD to trip. The low-voltage line distribution box and the user's electrical equipment are generally equipped with lightning arresters or surge protection devices. When the lightning strikes, the lightning protection device acts. These actions will cause the line leakage current to increase instantaneously so as to lead to Grade 1 protection to mis-acting.

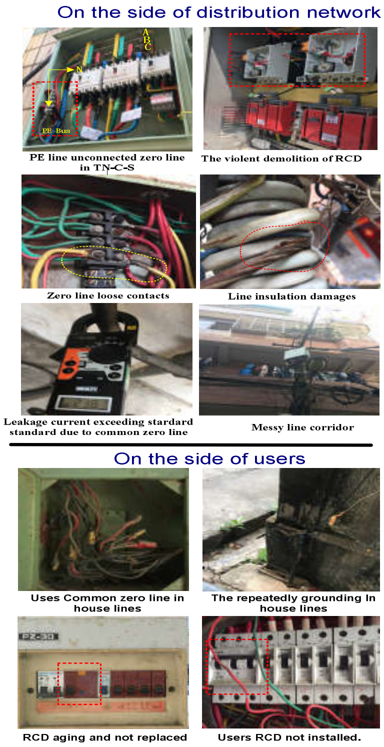


Fig.3 The actual operation statu

Figure 3 shows the actual operation status of a LV distribution network in a southern coastal city.

2 THE DETECTION METHOD OF LEAKAGE CURRENT

Normally, even if the leakage current of the line in wet weather is relatively large, the residual current of the normal operation low-voltage distribution system should not be greater than 20 mA in the downstream. Only 10 mA is for the downstream Grade 2 protection. And the residual current of the downstream Grade 1 protection system shall not exceed 50 mA with Small Capacity Distribution Transformer under 100kVA , and less than 150 mA with Big Capacity Distribution Transformer over 100kVA. The setting value of RCD current recommended by China National Technical Standard is based on the maximum residual current that the system is normally insulated to the ground and no malfunction in normal operation. Once RCD operates, the correct elimination of leakage point becomes a top priority in order to ensure the normal operation of RCD when one or more insulating failure points with excessive leakage current occur. Otherwise, if the setting value is set up high unreasonably or the system still delivers electricity by force after the RCD is withdrawn from operation, it will be unable to play a protective role in the occurrence of electric shock accidents, and also leads to accidental leakage accidents. It will bring about serious consequences. For example, when the leakage point is flooded, pedestrians walked in the water will be electrocuted. In addition, the leakage arc may also cause fire when the line operates at the leakage point for a long time.

2.1 Live working search method

A leakage detecting instrument is used to find out the leakage point of the circuit while RCD is temporarily withdrawn from operation or its current setting value goes up at a switch-on.

A commonly used leakage detecting instrument is a portable clamp-type multimeter, as shown in figure 4. From the RCD installation site as a starting point, the staff looks for a suitable place for the measure along with the line, uses the probe of the detector to hold the three-phase or single-phase conductor (for single-phase load line) along with the neutral line, and reads out the residual current measurement value. If the residual currents of the two adjacent measuring points on the line are significantly different, it is a judgment that there is a leakage point with damaged insulation between the two points. For example, if the residual currents decrease from 150 mA to 50 mA at two adjacent measuring points, it states that there are abnormal leakage points in this line.

Fig.4 The portable clamp multimeter

Actually, the working conditions are quite complicated in distribution boxes and distribution lines. In some cases, the clamp probe of the multimeter cannot hold the conductor and the neutral line. For this situation a conductor and a neutral line can be held by a flexible Roche coil. The output signal is transferred to a special portable instrument to measure the residual current. As shown in Figure 5.

Fig.5 Portable Residual Current Detection Device

For loads with low power supply continuity requirements, if switches or fuses are installed downstream of the RCD, the pull-out exclusion method can also be used to narrow the inspection range. Specifically, first, the instrument is used to measure the residual current at the upstream of the line switch (fuse), and then open and close the upstream and downstream branches one by one. If the residual current measured has a significant drop when a certain branch switch is opened, it states that the leakage places on the disconnected branch.

2.2 Off-line detection method

Fig.6 Leakage current location device based on injection signal method

Off-line detection method refers to injecting an interharmonic signal (e.g. 225Hz) between the conductor and the earth when the line is out of power. Then, a movable probe is used to detect the magnetic field intensity around the line, and find out the leakage point according to the change of the magnetic field intensity. The reason is why the injection signal will return from the leakage point and the magnetic field generated by the injection signal can only be detected in the area ahead of the leakage point at the condition of ignoring the ground capacitance and conductance of the line. Therefore, once the instrument detects a significant change in the magnetic field of the line, that is to say, the location of the leakage point is nearby. Fig. 6 shows the magnetic field intensity curve detected above the single-phase line in the trench. It is evident that the magnetic field intensity decreases sharply behind the leakage point.

Actual distribution lines exist the capacitance and conductance to ground and the grounding point (leakage point) also has a large grounding resistance. Therefore, a bit of injection current signal will flow to the area behind the leakage point. Additionally, the magnetic field around the circuit is related to the strong or weak of the injected signal, the environment of the buried circuit and the position of the probe of instrument. In real application, the position of leakage point should be able to confirm by synthetically thinking about the change of magnetic field intensity measured and the actual situation on site. Generally speaking, under the identical measuring environment and conditions, if it is found that there is a significant change in the magnetic field intensity within a few meters, it can be judged that there is a leakage point on the nearby line.

This method is especially suitable for detecting leakage points of lines buried in underground and wall.

3 RELEVANT MEASURES FOR RETROFIT AND RENOVATION

3.1 Exert the Government-led Role

Electricity safety is an important part of social and public safety. The government plays a leading role in promoting the popularization and application of RCD and can solve problems in RCD installation that un-follow technical standards. In particular, some of public facilities, such as fountains, municipal streetlights, light box advertisements and other devices, easily cause electric shock in water. Therefore, practical measures should be taken to urge relevant responsible units to install RCD and leave no blind zones. It's needed to promote the application of residual current protection through legal means and improve the laws and regulations on electric shock protection.

3.2 Improve the Running Rate of RCD

Because the leakage current exceeds the standard, RCD cannot be put on, which is the main problem restricting the improvement of the application level of residual current protection at present. Measures should be taken to solve this problem:

Renovate the severely aging circuit can meet the needs of the residual current in normal operation. Regulate the problem of common zero line and serial zero line. As for the municipal services, streetlights, communication lines and other circuits, the problems that they are hung on the low-voltage distribution lines and share zero lines or cross zero lines, have resulted in false leakage current exceeding the standard, and thus the RCD cannot be put on, so the line transformation must be coordinated with the municipal services, streetlights, communication department and other departments.

The installation of lightning protection device is in parallel with the protection installation. Measures should be taken to avoid the RCD action caused by lightning strike.

The residual current online monitoring system should be reconstructed, and the existing RCD generally has a communication interface to create conditions for the realization of residual current online monitoring. It is needed to real-time monitor and track the changes in the residual current of the line, and the operation and maintenance personnel should timely grasp the status of line insulation and RCD, so as to conduct the targeted operation and maintenance for them.

3.3 Focus on Solving the Problem of Electric Shock Protection in Water

In the swimming pool, waterscape fountain, water amusement park, and shower room as well as flooded public electric facilities nearby, it is prone to electric shock accident in water. When somebody is shocked in the water with electric leakage, the electric current direction to pass through his/her body is complicated. The current intensity is closely related to the water purity, the water temperature, and the distance between the leakage point and the position of the human body. And the risk is much higher comparing with other occasions. Electric shock accidents in water are unforeseen. The rescue is difficult and often incur a group of persons to dead and wounded. During the 2018 rainy season, there have been many electric leakage and injury accidents caused by flooded public power facilities nearby in Guangdong, Fujian and other places in China. After the CCTV reported these accidents, the problem has aroused great social concern.

Overall, it must ensure that the residual current protection measures of line and electrical equipment are in place, to eliminate the blind zone of RCD protection installation, to check and maintain the distribution system and RCD periodically, and promptly to find out the potential risk of leakage and device rejection. Once the RCD tripping is found, the leakage point should be searched in time, measures should be taken to eliminate the potential risk, and the power transmission will be banned after withdrawing from the protection or raising the action value. As far as possible, the RCD with perfect functions can be used to monitor the residual current on line.

3.4 Standardized Renovation of Distribution Transformer Station Area

A potential and long term risk of electric shock in the low-voltage system is incurred by non-standard and non-standardization of the low-voltage distribution equipment and circuits in the area. In some regions of China, some of power supply enterprises do not pay enough attention to the grounding mode. The TN-C system is not equipped with repeated grounding/equipotential connection. The repeated grounding resistance is not in accordance with the standard (< 10 Ω). The PE line of the TN-C-S system is not grounded. The TT system and the TN-C system are mixed. So we should standardize the low-voltage grounding mode, take measures according to the local conditions, widely adopt the pole-type transformer and the TT system connection mode for the rural areas and rural-urban fringe zones. The TN system should be selected and applied in urban power distribution room, and two kinds of standardized grounding mode schemes for selection are given as shown in the following Fig. 7 and 8.

Fig. 7 TT System RCD Hierarchical Protection System Construction

Fig. 8 Repeated Grounding Settings of TN System

CONCLUSION

In conclusion, among the existing three levels of protection, only the last level of the household protection can guarantee personal safety. The general protection and the middle protection have a stated current action value of more than 100 mA, which is in fact difficult to guarantee the safety of the person who is shocked. As for the current pulse protection and the amplitude discrimination and phase discrimination protection, there exists action blind zones, and frequent disoperation occurs in the actual operation process. The phasor mutation protection put forward by some scholars is a promising protection principle, but the number of field applications is still limited and lack of operational experience. And in principle, this protection also needs to solve the problem of frequent disoperation caused by the normal variation of the residual current. Some scholars have discussed how to realize the protection of electric shock by using the difference between the characteristics of human body electric shock and the normal residual current of the line. At present, it is only staying in the stage of theoretical discussion, and there is still a certain distance from the practical application. A lot of research work is needed to solve the problem of poor electric shock protection effect of general protection and middle protection.

In addition, the residual current protection is not suitable for TN-C systems. For more and more TN-C-S systems, due to the direct grounding of the neutral line at the inlet of the distribution box, there is the residual current on the trunk line due to the unbalanced load under normal operation conditions. So the general protection cannot be installed at distribution transformer. How to solve the problem of electric shock protection in TN-C system and TN-C-S system is also an important content in the research of electric shock protection technology.

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