Study on Outdoor Terminal Box Moisture-proof Measures

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Abstract. The paper analyzes the components of outdoor terminal box, and studies the mechanism of outdoor terminal box moisturizing according to the relationship between temperature and humidity, and proposes the main ideas of moisture-proof outdoor terminal box. Through wide range of investigation, the paper teases out the current moisture-proof measures of outdoor terminal box and analyzes the effect of each measure according to the actual operation. By counting the damp defects of outdoor terminal box, the paper analyzes the hidden danger of outdoor terminal box moisturizing and the reasons why the frequency of some terminal boxes moisturizing is high. Finally the paper proposes some advice for moisture-proof measures of outdoor terminal box in southern area.

1. Introduction

Terminal box is used to place secondary devices such as relays and terminal strips and is usually put beside the corresponding primary equipment [1,2]. As outdoor terminal box is directly exposed to the external environment without house protection, the working condition is worse than the one of indoor terminal box. Especially as the humidity in southern area is high for long, the moisturizing problem of outdoor terminal box is much more serious [3,4].

At present research on outdoor terminal box mainly includes moisture-proof device development and moisturizing problem analysis of field outdoor terminal box. In terms of moisture-proof device development, literature [5] proposes a moisture-proof device based on the temperature inside and outside the terminal box to control heater and exhaust fan, which has a good energy-saving effect. Literature [6] proposes to add semiconductor refrigeration based on traditional heating moisture-proof and monitor device status wirelessly by Zigbee network. Literature [7] adopts WSN and semiconductor refrigeration and realizes rapid temperature control and moisture-proof by online variable gain PID control.

The research above makes some progress on improving dehumidification device performance and enhancing energy-saving effect and intelligence of moisture-proof device, but there are some problems as follows: 1) The cost of semiconductor refrigeration is high and not suitable for large scale application. 2) Factors of outdoor terminal box moisturizing are complicated, and merely relying on moisture-proof device may not achieve a good effect.

Literature [8,9] analyzes field outdoor terminal box moisturizing problems. Literature [8] proposes some moisture-proof measures such as modifying heater start value in time according to weather conditions to solve the problem of Qingxi substation outdoor terminal box moisturizing. Literature [9] conducts research on Hanjiang substation outdoor terminal box moisturizing problems, which compares the moisture-proof effect of heater adopting constantly turning on strategy and heater adopting temperature and humidity control. The research above put forward some moisture-proof...
advice in accordance with field operation experience, but do not conduct system analysis on outdoor terminal box moisturizing reasons, and the advice proposed is incomplete.

In order to solve the outdoor terminal box moisturizing problem entirely, it is necessary to conduct deep analysis on outdoor terminal box moisturizing reasons and make some improvements for the current moisture-proof measures deficiency. At present few researchers tease out the structural design, moisturizing reasons and current moisture-proof measures of outdoor terminal box systematically. Literature [10] analyzes a few kinds of moisture-proof measures simply, but the moisture-proof measures analyzed are insufficient and the literature do not put forward renovation advice. The paper deeply analyzes the structural composition and moisturizing mechanism of outdoor terminal box and proposes the main ideas of outdoor terminal box moisture-proof accordingly. Then the paper teases out the current outdoor terminal box moisture-proof measures systematically through wide range of investigation and analyzes each measure’s practical effect. Finally, the paper analyzes the outdoor terminal box moisturizing defects in southern area and proposes moisture-proof advice.

2. Structural composition of outdoor terminal box

Though there are great varieties of outdoor terminal box, the major structure is almost the same shown as the figure below, which mainly includes box, door, vent, cable inlet.

![Figure 1. Typical structure of outdoor terminal box](image)

2.1. Box

Box is the main part of outdoor terminal box, which is used to place relays and terminal strips. The box is usually made by 304 stainless steel (312 stainless steel in coastal area) or galvanized steel, which has an advantage of lightweight but has disadvantages of bad thermal insultation property and temperature inside the box changing fast with environmental temperature. Some boxes with bad workmanship are easy to rust at the welding points.

2.2. Door

2.2.1. Door sheet. The door sheet’s material is usually same as the box. Some terminal boxes have two layers of doors. The outer layer is used to open and close the box. The inner layer is used to place some relays and power switches.

2.2.2. Sealing strip. When the door is closed, there is still a gap between the door and the box. In order to increase the sealing margin, the interface between door and box is usually placed a sealing strip. The structural type of sealing strip mainly includes rectangle sealing strip and self-clamping sealing strip. There are no skeletons inside the rectangle sealing strip, so when installing, the rectangle sealing strip needs to be cut into 4 pieces and place at the 4 borders of the door or the box and then connect the 4 pieces. The self-clamping sealing strip inside has a steel wire core and can be installed for a whole and has a more rigorous sealing structure and thus has a better sealing performance.
2.2.3. **Door lock.** The door lock is used to fix the closed door to the box, which mainly includes screw locking, pathway locking and plate locking shown as the figure below.

![Door Lock Types](image)

**Figure 2. Lock structure type**

2.3. **Vent**

Most outdoor terminal boxes have vent, which is used to circulate the air of the box. The design of vent location is diverse. The four side and the bottom of the box can configure vent. The vent usually has rain-proof measure to avoid rainwater directly infiltrating.

2.4. **Cable inlet**

Cable inlet is usually set at the bottom of the box. The cable inlet of dangling terminal box is far from the ground, and the one of floor type terminal box is close to the ground, which is easy to be corroded when the ground air is wet in rainy weather. Especially if there is a cable chute under the box, corroding will be more serious because the cable chute is easy to accumulate water in rainy days.

3. **Moisturizing mechanism of outdoor terminal box**

3.1. **Concept of condensation**

The saturation water vapor pressure of air $E$ indicates the maximum water vapor content that the air can absorb under certain conditions. Relative humidity RH indicates the ratio of the current water vapor pressure and the saturation water vapor pressure, the relationship among saturation water vapor pressure $E$, relative humidity RH and temperature $T$ is shown as the figure below.

![Condensation Graph](image)

**Figure 3. Relationship between saturation vapour pressure, relative humidity and temperature**

It can be seen from the figure that as the temperature drops, the maximum water vapor content that the air can absorb decreases, and the air relative humidity increases. When the temperature drops to a certain value, the air relative humidity increases to 100%, and the temperature at this moment is called dew point temperature. The water vapor in the air will congeal. It is worth noting that as the temperature decreases, the rising speed of relative humidity increases. So if the temperature drop is large, the air will quickly turn into saturation status, which leads to condensation.
3.2. Moisturizing mechanism analysis
It can be known from the outdoor terminal box structure that the outdoor terminal box is not completely sealed, and there are 4 connection passageways between the outdoor terminal box and the external environment: 1) vent, 2) cable inlet, 3) the gap between the box and the door, 4) the damaged points and the loose points of the box.

There are 2 ways for outdoor terminal box to be moisturized:
1) In rainy weather, rainwater infiltrates into the box through weak rain-proof points such as the corroding points of the box and leads to moisturizing.
2) When the outside air is wet, the wet air will flow into the box through the connection passageways mentioned above. Especially for the terminal box that has vent, or the box whose cable inlet is not strictly sealed, or whose sealing strip loses efficacy, or the floor type terminal box, the wet air can flow into the box more easily. As the thermal insulation property of outdoor terminal box is bad, the temperature inside the box changes fast with environmental temperature. As environmental temperature decreases at night, the temperature inside the box decreases, and the air relative humidity inside the box increases. When the air relative humidity comes to 100%, condensation happens in the box and leads to moisturizing.

It can be concluded from the analysis above that there are 2 factors in outdoor terminal box moisturizing: 1) the wet air or rainwater goes into the box through the 4 connections and makes the water vapor content inside the box be high (if the rainwater goes into the box, the box will be directly moisturized), 2) the temperature inside the box drops to the dew point temperature and leads to condensation.

Therefore, the key of outdoor terminal box moisture-proof is to destroy the 2 factors above, and the main ideas include: 1) cutting off the connection between the box and outside environment, 2) decreasing the water vapor content inside the box, 3) increasing the temperature inside the box.

4. Outdoor terminal box moisture-proof measures

4.1. Ventilating dehumidification
Ventilating is a widely used design for terminal box. The wet air inside the box is expelled to the outside through the vent, and some terminal boxes have a fan to strengthen the ventilating effect. However, in terms of the practical performance in southern area, ventilating dehumidification does not have an obvious effect, and is even bad for outdoor terminal box moisture-proof. It is because the climate in southern area is wet, and the environmental humidity is high, and the outside wet air can easily go into the box through the vent, leading to much condensation. So ventilating dehumidification is suitable in dry environment, but in wet environment it is adverse for dehumidification.

4.2. Heating dehumidification
Heating dehumidification is a widely used moisture-proof measure in terminal box, which is to install heaters inside the box and control the heaters according to certain strategy to increase the temperature inside the box and thus decrease the humidity inside the box. The concrete number of heaters, the power of heaters and the location of heaters are different according to the manufacturers design and the terminal box size.

The heater control strategy mainly includes: 1) the heater is constantly turning on, 2) the heater is controlled by temperature and humidity, 3) the small power heater is constantly turning on, and the large power heater is controlled by temperature and humidity. In terms of field practical performance, the effect of heating dehumidification of some boxes is limited. It is because:

(1) the thermal insulation property of outdoor terminal box is bad, and the temperature rise caused by the heaters is limited.
(2) heating can only decrease the relative humidity and cannot decrease the absolute humidity. So if the wet air outside goes into the box constantly, when the temperature drops, condensation still easily occurs.
(3) some outdoor terminal boxes are large, and the location of heater is far from the relays and terminal strips. Because of the limitation of the heater power, the temperature around the relays and the terminal strips do not rise effectively.

(4) when the temperature drop is large, the air will go into saturation status quickly. The heater controlled by temperature and humidity often cannot control the temperature into a reasonable range in time in this situation.

4.3. Dehumidifying box
Dehumidifying box uses chemical substances to absorb the water vapor in the air such as calcium chloride, silica gel or activated carbon. According to the field practical performance, the effect of dehumidifying box is good, but the effective constituent in the dehumidifying box is limited, and the box needs periodic replacement.

4.4. Terminal box sealing
Cutting off the connection passageways that the outside water vapor goes through is an effective approach to reduce water vapor content in the box and reduce condensation. The connection passageways include: 1) vent, 2)cable inlet, 3)the gap between the box and the door, 4) the damaged points and the loose points of the box.

(1) Vent sealing  
For the problem of wet air going into the box through vent, using fireproofing mud to seal the vent is an effective measure.

(2) Cable inlet sealing  
1) Use fireproofing cotton to seal the cable inlet. In terms of the field practical performance, the sealing effect of fireproofing cotton is bad. If not coordinated with other sealing measures, little animals and wet air are easy to go inside.
2) Use fireproofing mud to seal the cable inlet.
3) Use PG splice to seal the cable inlet. In terms of the field practical performance, the sealing effect of fireproofing cotton is good.
4) For the problem of wet air in the cable duct corroding floor type terminal box, raising the terminal box by ascending flanged base of which the four sides are configured vents is an effective approach to expel out the wet air in the cable duct. For the terminal box that cannot be renovated, installing some ventilating cover board on the cable duct can evacuate the wet air in the cable duct.

(3) Sealing the gap between the box and the door  
Use a good quality sealing strip at the interface between the box and the door. The lock uses multipoint locking type.

(4) Box sealing  
Smear sealant at the welding points. Use integrated technology decreases the welding points.

4.5. Small air conditioner
Installing small air conditioner in some large outdoor terminal boxes to congeal water vapor and expel out through specialized pipeline is an effective dehumidification approach, but the cost is high, and the application is few.

4.6. Semiconductor refrigeration
The principle of semiconductor refrigeration is to utilize temperature variation effect of semiconductor material to congeal water vapor. Similar to small air conditioner, the cost of semiconductor refrigeration is high, and the application is few.
5. Moisturizing defect analysis of outdoor terminal box in southern area

5.1. Hidden danger of outdoor terminal box moisturizing

According to the field operation of outdoor terminal box, count various kinds of hidden danger of outdoor terminal box moisturizing that arises shown as the figure below.

![Figure 4. Hidden danger of outdoor terminal box damping and corresponding frequency](image)

It can be seen from the figure that the hidden danger of outdoor terminal box moisturizing mainly includes dehumidification device fault, cable inlet lax sealing, door unable to close tightly, power supply of dehumidification device disconnecting, box lax sealing, sealing strip losing efficacy. The reasons of hidden danger arising are shown as the table below.

| Hidden danger                           | Reasons                                                                 |
|----------------------------------------|-------------------------------------------------------------------------|
| Dehumidification device fault          | Temperature and humidity controller fault, semiconductor refrigeration fault, heater fault, fan fault |
| Cable inlet lax sealing                | Sealing missing, bad sealing quality of fireproofing mud, fireproofing mud falling off or crazing |
| Door unable to close tightly           | Lock/doorknob damage, rotating parts of the door damage                 |
| Power supply of dehumidification       | Air switch off, wire burnout, small animals going inside leading to short device disconnecting |
| device disconnecting                   | circuit                                                                  |
| box lax sealing                        | Rust on the box, water seepage at the box screw, box damage caused by force |
| sealing strip losing efficacy          | Sealing strip aging or distortion                                       |

In the hidden danger of dehumidification device fault, temperature and humidity controller fault accounts for 44%, and the problem exits in most manufacturers terminal box, so the reliability of current temperature and humidity controller is not high.

In the hidden danger of cable inlet lax sealing, sealing missing and bad sealing quality of fireproofing mud are problems of construction quality, and fireproofing mud falling off or crazing is caused by fireproofing mud aging.

In the hidden danger of door unable to close tightly, lock/doorknob damage and rotating parts of the door damage are caused by abrasion or poor quality.

In the hidden danger of power supply of dehumidification device disconnecting, air switch off and wire burnout are caused by the long-term heat from the large power heater leading to wire insulation decreasing or burnout. Small animals leading to short circuit is because the box sealing property is bad and small animals go inside.

In the hidden danger of box lax sealing, rust often appears at the welding points, and water seepage at the box screw is caused by the loose screw.

The reasons of sealing strip losing efficacy include sealing strip arriving to service life, high temperature or abrasion leading to sealing strip damage.

5.2. Some typical outdoor terminal box with high moisturizing frequency

According to the field operation of outdoor terminal box, count various kinds of hidden danger of outdoor terminal box moisturizing that arises shown as the figure below.
5.2.1. A switch mechanism box. The figure below is a switch mechanism box. The box has vent. The heater is set at the bottom of the box and is controlled by temperature and humidity. The reasons of the box moisturizing include: 1) The vent enables the wet air easy to go inside. 2) When temperature drops deep at night, the heater cannot control the temperature into reasonable range in time.

![Figure 5. Terminal box of a switch in certain substation](image)

5.2.2. A CVT terminal box. The figure below is a CVT terminal box. The height of the terminal box is more than 1.5m. The box does not have vent and uses rectangle sealing strip, and the 4 corners of the sealing strip have a huge gap. The box only has 1 heater which is controlled by temperature and humidity, whose location is at the bottom of the box. The reasons of the box moisturizing include: 1) The sealing property of the rectangle sealing strip is bad, and the wet air is easy to go inside. 2) The volume of the box is large and the heater is far from other secondary device and unable to provide enough temperature rise. 3) When temperature drops deep at night, the heater cannot control the temperature into reasonable range in time.

![Figure 6. Terminal box of a CVT in certain substation](image)

5.2.3. A circuit breaker terminal box. The figure below is a circuit breaker terminal box. The height of the terminal box is more than 1.5m. The box does not have vent. The cable inlet uses fireproofing cotton to seal, and there is small animal trace on the fireproofing cotton. The lock part of the sealing strip is worn. The box only has 1 heater which is controlled by temperature and humidity, whose location is at the bottom of the box. The reasons of the box moisturizing include: 1) The sealing effect of fireproofing cotton is bad, and the wet air is easy to go inside. 2) The configuration of lock and sealing strip is unreasonable. The sealing strip at the front of the box is worn by the plate-locking type lock, and the sealing effect becomes worse. 3) The volume of the box is large, and the heater is far from other secondary device and unable to provide enough temperature rise. 4) When temperature drops deep at night, the heater cannot control the temperature into reasonable range in time.
According to the analysis above, the terminal box with high moisturizing frequency has at least some of the features below:
1) the box has vent.
2) the box uses rectangle sealing strip of poor quality.
3) the height of the terminal box is more than 1.5m, and the heater is placed at only certain place.
4) the cable inlet uses fireproofing cotton.
5) the heater only starts working when temperature is below a value, and if temperature drops deep, the heater cannot control the temperature into reasonable range in time.

6. Moisture-proof advice for outdoor terminal box in southern area

It is concluded from the analysis above that the main ideas of moisture-proof include: 1) cutting off the connection between the box and outside environment, 2) decreasing the water vapor content inside the box, 3) increasing the temperature inside the box. Combining the defect analysis in section 4, the paper proposes the moisture-proof advice for outdoor terminal box in southern area as follows:

1) Cut off the connection between the box and outside environment
   1) According to the practical performance in southern area, the vent makes the wet air outside easy to go into the box, so it is recommended to seal the vent and the new terminal box does not configure vent.
   2) The sealing effect of fireproofing cotton is bad, and the fireproofing mud has the problem of falling off or crazing due to aging, so it is recommended that the cable inlet uses PG splice.
   3) The rectangle sealing strip has the problem of 4 corners jointing, so it is recommended to use self-clamping sealing strip.
   4) If the lock is plate-locking type and the sealing strip is placed at the front of the box, it is recommended that the lock is changed to other type or the sealing strip is placed at the door.

2) Decrease the water vapor content inside the box
   The volume of the terminal box whose height is more than 1.5m is large, and only relying on heater is not enough according to field operation, so it is recommended to add dehumidifying box, and install small air conditioner or semiconductor refrigeration when necessary.

3) Increase the temperature inside the box
   Because 1) constant heating of large power heater is easy to result in wire short circuit or burnout, 2) and only placing heater at certain place leads that the temperature rise is asymmetrical, 3) and the current fault rate of temperature and humidity controller is high, and if the heater is controlled by temperature and humidity, the heater may not control the temperature into reasonable range in time when temperature drops deep, so it is recommended that the heater uses the configuration of ‘small power and multipoint’, which means several heaters of small power are arranged symmetrically beside the secondary devices including relays and terminal strips, and the heaters are turned on constantly.

7. Conclusion
The paper deeply analyzes the structural composition of outdoor terminal box and moisturizing mechanism, and proposes 3 main ideas of outdoor terminal box moisture-proof. Through wide range
of investigation, the paper teases out the moisture-proof measures of outdoor terminal box systematically, and analyzes the practical moisturizing defects of outdoor terminal box in southern area. The result shows that configuring vent, using fireproofing cotton and using rectangle sealing strip have poor moisture-proof performance. Finally, the paper proposes pertinent moisture-proof advice according to the practical moisturizing defects in terms of 3 aspects including cutting off the connection between the box and outside environment, decreasing the water vapor content inside the box, and increasing the temperature inside the box.

References
[1] Zeng, X.Z. (2017) Design and Development of Outdoor Terminal Box and Mechanism Box Moisture Proof Monitoring System. South China University of Technology, Guangzhou.
[2] Zheng, X.X., Li, J.A., Song, S.B. (2018) Improvement and application of moisture-proof measures for outdoor terminal box in converter station. Electric Engineering, 15: 125-128.
[3] Xu, H, Yin, H.B., Liu, Q.Y. (2018) Solutions to the problem of condensation of substations in the south. Electrical Engineering, 19: 108-116.
[4] Li, Z.L. (2015) Research on weakness and precaution of HVDC converter station in wet environment. Electric Engineering, 12: 16-17.
[5] Jiang, Y., Zhou, C.H., Guo, J.F. (2010) Development and researching of intelligent controller for preventing condensation in terminal box. High Voltage Apparatus, 46: 59-62.
[6] Zhang, W.J., Cai, X.L., Gao, W. (2014) The development of the moisture and temperature control system for the terminal box in transformer substations. Electrical Measurement & Instrumentation, 51: 102-109.
[7] Xu, L.B., Gao, Y., Gao, W. (2017) Design of temperature-controlling and moisture-proof device for terminal box based on WSN and semiconductor refrigeration. Electrical Engineering, 18: 46-52.
[8] Xie, F.Q. (2014) Moisture-proof maintenance of outdoor terminal box in Qingxi station. Rural Electrification, 9: 19-20.
[9] Yin, C.M., Qiu, J.S., Huang R.Y. (2014) 500kV Hanjiang station terminal box moisture-proof system improvement research. China New Technologies and Products, 22: 57-58.
[10] Wang, W., Zeng, G.W., Lin, X.B. (2016) Research on terminal box moisture-proof strategy. Science Technology and Innovation, 24: 118-118.