The Application of Surface Potential Test on Hand-making Insulation for Generator Stator End-winding

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Abstract. This paper presents the advantage of surface potential test on hand-making insulation for generator stator end-winding insulation detection, compared with DC or AC withstand voltage test, also details the test principle, connection method and test notes. And through the case, surface potential test on hand-making insulation proved effective for insulation quality detection after generator stator end-winding maintenance, and the experimental data is useful and reliable for the electrical equipment operation and maintenance in the power plant.

1. Introduction
Domestic turbine generator stator end-winding with water-hydrogen-hydrogen cooling steam often exists all kinds of defects, such as: polyester glass rope fastening not strong enough, winding connection and lead wire joint exists insulation defects, insulation materials of insulation box filled not enough, stator winding hollow copper wire leakage caused by welding joint bad quality. In this area of stator end-winding, caused by thermal stress and all kind effects of mechanical stress during the operation, it may lead to insulation intensity weaken, easily to produce surface partial discharge, grounded short circuit or interphase short circuit. Therefore, the insulation detection for generator stator end-winding becomes particularly important\cite{1-2}.

2. Comparison between surface potential test with DC and AC withstand voltage test
DC and AC withstand voltage test is effective methods of generator stator end-winding insulation detection. The equivalent circuit of generator stator end-winding is shown in figure 1.
1. Stator iron core, 2. The insulation surface of stator end winding, 3. Stator winding, rs-Surface resistance per unit length, Rv-Volume resistance per unit length, Xc-Capacitive reactance per unit length

**Figure 1.** The equivalent circuit of generator stator end-winding

Assumed the voltage distributed along the infinite long winding, during withstand voltage test, voltage distribution of generator stator end-winding expressed by type (1).

\[ U_2 = U_1 e^{-\alpha L} \]  
\[ \alpha = \sqrt{\frac{r_s}{R_v}} \]  
\[ \alpha = \frac{1}{\sqrt{2}} \frac{r_s}{X_c} \]  

(1)

During DC withstand voltage test, the voltage distributes according to the resistance, and there is no capacitive current, leakage current flowing through the surface of the insulation is very small, the voltage of end-winding insulation is higher. While far from stator core, due to the role of the end-winding surface resistance, the voltage of end-winding insulation withstand reduces greatly. During AC withstand voltage test, the voltage distributes unevenly along stator winding caused by the effect of capacitive current of stator winding relative to the ground, while far from stator core, the capacitance current at the end of stator winding is smaller, and also the voltage of end-winding insulation withstand gets lower.

During DC and AC withstand voltage test, the voltage distribution curve of stator end-winding is shown in figure 2.

**Figure 2.** The voltage distribution curve of stator end-winding

DC withstand voltage test is easy to find the insulation defects of the stator end-winding, while AC withstand voltage test is easy to detect the insulation defects of the stator winding slots and notches. Surface potential test on hand-making insulation can be supplementary and auxiliary to partial insulation defect detection[3-4].
3. Connection method and principle of surface potential test

Surface potential test has positive and reverse connection two methods. In positive connection method, the stator winding withstands DC voltage, the winding connection and lead wire joint concatenates microampere meter and resistance to ground. However, in reverse connection method, the stator winding concatenates microampere meter and resistance to ground, the winding connection and lead wire joint withstands DC voltage.

In the condition of stator water cooling operation, and keep water quality qualified (In open water cooling system, water conductivity is not greater than 5.0μs/cm, in independent closed water cooling system, water conductivity is not greater than 2.0μs/cm), positive connection method cooperated with winding hydraulic pressure test can be used to detect stator winding hollow copper wire leakage caused by welding joint bad quality. In the condition of without cooling water, the stator cooling water pipe must be dry, surface potential test can both use positive or reverse connection methods. However, reverse connection method can only be used in the condition of without cooling water[5]. Positive connection method requires large capacity for test equipment, and is vulnerable to the influence of dirt level on the stator. However, positive connection method has obvious advantages. a) Positive connection method can use DC withstand voltage test equipment, is easy to carry out. b) In reverse connection method, the winding connection and lead wire joint withstands DC voltage, this may lead risk to the test personnel. c) In positive connection method, the concatenated resistance volume is fixed, it is easy to judge the relative degree of the insulation defects according to numerical change on microampere meter. However, in reverse connection method, leakage current flowed through microampere meter changes bigger, it is difficult to judge insulation defect levels by reading meter value.

When the stator winding withstands DC voltage, the equivalent circuit is shown in figure 3. \( R_1, C_1 \) respectively represents the insulation resistance and capacitance per unit volume of stator end-winding measured parts, \( R_2, C_2 \) respectively represents the insulation resistance and capacitance per unit volume except stator end-winding measured parts, \( R_3 \) represents concatenated resistance, usually its value is 100 MΩ, \( R_4 \) represents surface resistance per unit length of stator end-winding, \( R_Y, C_Y \) respectively represents resistance and capacitance of water collecting pipe for water diversion tube side, \( R_H, C_H \) respectively represents resistance and capacitance of water collecting pipe relative to the ground, \( R_X, C_X \) respectively represents the insulation resistance and capacitance relative to the ground except measured parts, PV,PA respectively represents electrostatic voltmeter and microampere meter.

![Figure 3](image_url)  
*Figure 3. The equivalent circuit of stator winding withstand DC voltage*

When there are no insulation defects in stator end-winding, the insulation resistance volume of stator end-winding \( R_1 \) is greater than the surface resistance \( R_4 \), voltage drop is mainly concentrated on the insulation resistance \( R_1 \), leakage current at point A is very small, the volume of electrostatic voltmeter is almost to zero. When there are insulation defects in stator end-winding, the insulation resistance volume of stator end-winding \( R_1 \) decreases and the voltage \( R_1 \) withstood also reduces, so leakage current at point A increases correspondingly, the volume of electrostatic voltmeter gets bigger. Therefore, when the volume of concatenated resistance \( R_3 \) is fixed, it is credible to reflect the insulation condition of stator end-winding according to the measured voltage value at point A[6-8].
4. Method of surface potential test

Surface potential test generally carries out before stator end-winding cleaning to detect potential insulation defects. In the process of test preparation for positive connection method, each stator end-winding connector and wire connector (three phase and neutral wire lead) cover with a thickness of 0.01 ~ 0.02mm aluminium foil. Aluminium foil wraps tightly and adjacent foils should not lap, in case of discharge current affects the measurement result produced by capacitance effect between foil paper and insulation surface when measuring rod contacts aluminium foil. Test data record should after data showed stable. Insulation resistance test should carry out before surface potential test.

The metal material probe at the top of measuring rod concatenates resistance and microampere meter to ground, the value of concatenated resistance usually chooses 100 MΩ, resistance capacity is 1~2W. Electrostatic voltmeter parallelly connects with concatenated resistance and microampere meter. In the process of surface potential test, according to the capacity of generator, the stator winding three-phase or each single phase applies DC voltage. Measuring rod detect each stator end-winding connector and wire connector, and record data value of electrostatic voltmeter and microampere meter. If discovering the abnormal phenomena such as leakage current imbalance, it should increase test voltage to locating defects position, but the pressure time should not be too long[9].

Test personnel must stand on insulation rubber mat, wear insulation gloves, and adopt high voltage security measures. After the test, each stator end-winding connector and wire connector should discharge to ground before removing aluminium foil, and attention should be paid to prevent the aluminium foil falls into generator.

5. Application case

During No. 3 turbine generator maintenance in a power plant produced by oriental motor Co., Ltd, model QFSN-330-2-20, rated power 330 MW, water-hydrogen-hydrogen cooling type, replaced part of the stator winding bar, and carried out hand-making insulation processing for stator end-winding connector and wire connector, using epoxy resin insulation materials. Epoxy resin roasted with tungsten lights to accelerate insulation solidified. After hand-making insulation processing, stator cooling water circulated normally and water quality met the requirement, to carried out surface potential test on hand-making insulation for generator stator end-winding. Each stator end-winding connector and wire connector of both excitation side and turbine side covered with aluminium foil, as shown in figure 4.

![Excitation side of stator covered with aluminium foil](image)

Using positive connection method of surface potential test, the stator winding three-phase applied DC voltage, test voltage selected stator rated voltage of 20kV, measuring rod type was KDG-II. Each Stator end-winding connector and wire connector of both excitation side and turbine side orderly numbered, and detected by using measuring rod, recorded data value of electrostatic voltmeter and
microampere meter. In the process of test found that the surface insulation voltage on phase B of the stator wire connector was 17.4kV and the surface insulation voltage on phase B of stator neutral wire was 7.0kV. These values were greater than required value in DL/T 596-1996 “electric power equipment preventive test regulations”.

After cut off test power supply and discharged to the ground, to check hand-making insulation condition for phase B of the stator winding, it found that the insulation package for phase B of the stator wire connector was not enough, the metal edge of copper wiring row was exposed, led to the voltage on insulation surface of the stator wire connector phase B abnormally increased, the scene photo was shown in figure 5.

![Figure 5](image)

(a) (b)

**Figure 5.** Insulation package for phase B of the stator wire connector

The insulation package for phase B joint of neutral wire and water diversion tube was also not enough, the copper hoop of water diversion tube was exposed and caused the voltage on insulation surface abnormally rose. The scene photo for phase B joint of neutral wire and water diversion tube was shown in figure 6, the scene photo for water diversion tube was shown in figure 7.

![Figure 6](image)

**Figure 6.** The joint of neutral wire and water diversion tube for stator winding phase B
The reason of defect analyzed that, during hand-making insulation processing, prematurely withdrew shaped mold before epoxy resin insulation material completely solidified, led to epoxy resin materials gravitated and dropped, or the epoxy resin material insulation package was not enough caused the metal joint exposed. These above reasons led to the voltage on insulation surface abnormally increased.

After rehandled hand-making insulation for phase B of the stator winding, the test results of surface potential test displayed that the surface insulation voltage on phase B of the stator wire connector was 0.1kV, and the surface insulation voltage on phase B of stator neutral wire was 0.2kV. The value of test data met the requirement of the regulation.

6. Conclusion
Compared with DC and AC withstand voltage test, surface potential test can be supplementary and auxiliary to detect partial insulation defect in hand-making insulation.

Compared with reverse connection method, positive connection method is more applied to surface potential test on hand-making insulation for generator stator end-winding

Surface potential test is a effective method to inspect quality of hand-making insulation handled after generator stator end-winding maintence.

7. Reference
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