Electronic Current Transformer Defects Statistical Analysis of Intelligent Substation

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Abstract. In order to master operation status of the electronic current transformer (ECT), application investigation and defects statistical analysis were conducted on ECT of 110(66)kV~1000kV applied in smart substation of the State Grid Corporation of China (SGCC). The defect location, defect cause and defect type of ECT with different principles are analyzed. The results indicate that the defects of ECT are mainly concentrated in the acquisition unit, the defect rate is closely related to the reliability of electronic components, the technical level, production process and quality control of the manufacturer. In view of the typical defect analysis, the corresponding solution measures are put forward to provide reference for the subsequent research and application of ECT.

1. Introduction
ECT has the advantages of advanced principle, simple insulation structure, large dynamic range, fast transient response and good system integration. It is an advanced power measurement technology with remarkable achievements in energy saving, emission reduction, environmental protection and sustainable development\cite{1-4}.

In 2009, the SGCC comprehensively promoted the construction of smart substations, and a large number of electronic transformers were adopted. The low reliability of electronic transformers was exposed in the use process. In order to improve the quality and performance of products and promote the engineering application of electronic transformers, SGCC has carried out the performance test of electronic transformers. By the end of 2011, the first batch of performance tests were completed, including 41 samples from 24 manufacturers, among which 4 samples from 3 manufacturers passed the performance tests. By the end of 2012, the performance tests of 75 electronic transformers had been completed, and a total of 19 samples passed the performance tests\cite{5-8}.

Through professional testing and the accumulation of operating experience, factories had fully understanding on electromagnetic compatibility (EMC) problem, temperature and vibration reliability of acquisition unit and took the corresponding measures, reliability of electronic transformer had been improved significantly. At the end of 2013, SGCC built six new generation of intelligent demonstration substations. In 2015, another 50 expanded demonstration stations were planned and constructed.

By the end of 2019, the longest operation time of the active ECT is 14 years, the longest operation time of the passive all-fiber ECT is 11 years. In order to fully understand the operation status of ECT, this paper makes statistics on the application of ECT and the defects occurring during operation in the
smart substation of SGCC, analyses the position, cause and type of defects of ECT with different principles, and puts forward corresponding solutions to provide reference for the research and application of ECT in the future.

2. Principle and application of ECT

2.1. Principle of ECT

It can be divided into active ECT and passive all-fiber ECT according to whether the primary acquisition unit needs power supply.

Active ECT is superior to passive all-fiber ECT in terms of temperature characteristics and anti-vibration performance, and has high accuracy in small current. Acquisition unit of active ECT used for air insulated switchgear (AIS) is at the high-voltage primary side, which requires the high-voltage energy supply system.

Because there is no direct electrical connection between the passive all-fiber ECT acquisition unit and the fiber coil, it is superior to active ECT in anti-electromagnetic interference. Passive all-fiber ECT does not need the high-voltage energy supply system, so the energy supply reliability is high. However, the small current accuracy of passive all-fiber ECT is easily affected by white noise.

2.2. Application of ECT

As of December 2019, 6609 ECT units of 110 (66) kV and above have been put into operation in SGCC, including 5268 active ECT units and 1341 passive all-fiber ECT units, involving 195 substations. The application of ECT is shown in Table 1. Active ECT was applied earlier and in large quantity due to its relatively simple principle and high cost performance. Due to the late maturity of technology and high price, passive all-fiber ECT has less operation than active ECT. The application of passive all-fiber ECT has been increasing in recent years with the improvement of the home-made rate of optical devices and the maturity of technology.

| Classification   | Number of Units in Operation (Units) |
|------------------|--------------------------------------|
| Active ECT       |                                      |
| 110 (66) kV      | 2997                                 |
| 220kV            | 1635                                 |
| 330kV and above  | 636                                  |
| summation        | 5268                                 |
| Passive all-fiber ECT |                                  |
| 110 (66) kV      | 651                                  |
| 220kV            | 603                                  |
| 330kV and above  | 87                                   |
| summation        | 1341                                 |
| Total            | 6609                                 |

3. Defect statistics and analysis

3.1. Defect statistics and analysis of active ECT

Defects of active ECT put into operation after 2013 occurred 95 times, including acquisition unit defects 58 times, power system defects 12 times, sensor defects 4 times, transformer body defects 4 times, fiber insulator defects 3 times, defects location could not be determined 14 times. The defective part distribution is shown in Figure 1. The causes and types of typical defects of active ECT were analyzed, and the corresponding solutions were put forward.
3.1.1. Damage of components in acquisition unit
Defect cause: The acquisition unit is located in the primary body, the working environment is relatively harsh; Insufficient anti-interference design, unreasonable device selection, improper protection and imperfect self-inspection leads to easy damage; The PCB production technology of acquisition unit is deficient.

Defect type: Device quality problem; design problem; quality control problem; manufacturing process problem.

Solutions: Strengthen the low-power design and heat dissipation measures of the acquisition unit, and fully consider the temperature and humidity requirements of the operation site when selecting components; Strengthen the quality control of acquisition unit, select high-quality components, strengthen in-factory testing, optimize device management and real-time monitoring; Strengthen testing, improve testing standards.

3.1.2. Abnormal output of acquisition unit caused by disconnecting switch operation
Defect cause: The defects are mainly concentrated in active ECT for GIS. Although the acquisition unit is at ground potential, due to the serious VFTO generated by the gas insulated switchgear(GIS) transient process, the transient disturbance may be transmitted from the sensor to the acquisition unit and affect the signal port; Transient ground potential lift may be transmitted to the acquisition unit and affect the power supply port; The tank of GIS products is designed and produced by the GIS manufacturer, the transformer manufacturer only provides the sensor and acquisition unit, in this way, EMC is not designed as a whole; In the early stage, there were many manufacturers, the technology level was uneven and the understanding of EMC design was insufficient; The VFTO generated by disconnecting switch operation is related to GIS structure and grounding processing.

Defect type: Design problem.

Solutions: In view of the characteristic that the acquisition unit of ECT moves forward to the primary equipment site, strengthen EMC design and strengthen anti-interference design from the aspects of structure, hardware and software; The electronic transformer manufacturer shall carry out unified design, production, manufacture and test on the whole electronic transformer for GIS (including tank, primary sensor and acquisition unit), the integrated structural design method shall take anti-electromagnetic interference into consideration; The tank is integrated with primary sensor and collection unit, and the small analog signal obtained by sampling is transmitted to acquisition unit in very short distance and in a good electromagnetic environment; Improve the EMC detection requirements, and strengthen the disconnecting switch anti-interference test; Optimize GIS structure design and perfect GIS grounding.

3.1.3. Unstable or damage of laser energy supply module
Defect cause: Active ECT used for AIS is powered by a combination of CT energy and laser energy. When the switching design of laser energy supply and CT energy supply is unreasonable, it is easy to
cause abnormal state of the acquisition unit or inaccurate measurement; The change of ambient temperature affects the conversion efficiency of the laser module; The laser power connector has certain requirements for dust and static electricity, the optical fiber operation in production and installation is not standardized, the optical fiber splice is polluted by dust, and the laser heat dissipation is poor, etc., which causes the laser failure.

Defect type: Design problem; installation problem.
Solutions: Design reasonable switching mode of energy supply, appropriately reduce the starting current threshold of CT energy supply, reduce the working time of laser power supply, improve the service life of laser power supply, and ensure the smooth switching of the two ways of energy supply; Optimize the circuit design, reduce the power consumption of the acquisition unit, improve the conversion efficiency of the laser power supply module, and improve its ability to adapt to environmental temperature changes; Standardize the optical fiber plugging in the process of installation, increase the inspection and cleaning operation to the optical fiber of laser power supply, add dustproof measures, and strengthen the design of heat dissipation.

3.1.4. Unreliable connection of coaxial cable in acquisition unit
Defect cause: The terminals of signal coaxial cable adopt crimp contact, if the pressure is not enough, factors such as vibration in operation may cause the contact to be unreliable.
Defect type: Manufacturing process problem.
Solutions: The production process of coaxial cable should be changed to pressure welding, the inspection of key quality points should be strengthened, and the key quality points should be checked one by one.

3.1.5. Internal condensation and water accumulation.
Defect cause: Parts of the product terminal box are unsmooth machined, resulting in poor sealing performance, long-term operation leading to internal water inflow; When the active ECT is integrated with the disconnecting circuit breaker, the primary sensing part is generally installed outside the connection flange of the circuit breaker, poor sealing resulting in internal water inflow.
Defect type: Manufacturing process problem.
Solutions: Strengthen the sealing manufacturing control in the production process.

3.1.6. Excessive loss of optical path or insulation breakdown of optical fiber insulator
Defect cause: Improper selection of filling materials, expansion and contraction of the fiber under external stress, resulting in the increasing of fiber loss; Due to the poor glue filling process, there is air gap in some fiber insulators, which leads to insulation breakdown during operation.
Defect type: Manufacturing process problem.
Solutions: Choose appropriate filling material; Improve the level of glue filling technology.
In summary, the defects of active ECT are mainly concentrated in the acquisition unit and energy supply system, and the defects are closely related to the technical level, production process and quality control of the manufacturer. Acquisition unit components reliability, acquisition unit EMC design and laser power module reliability are still difficult problems. To improve the reliability of active ECT, it is necessary to optimize low power design of acquisition unit, switching method and circuit design of laser power supply, EMC protection design, etc., and strengthen selection and quality control of lasers, photoelectric conversion module, AD conversion module.

3.2. Defect statistics and analysis of passive all-fiber ECT
Defects of passive all-fiber ECT put into operation after 2013 occurred 110 times, including acquisition unit defects 106 times, transformer body defects 4 times. The defective part distribution is shown in Figure 2. The causes and types of typical defects of passive all-fiber ECT were analyzed, and the corresponding solutions were put forward.
3.2.1. Damage of components in acquisition unit
Defect cause: Insufficient anti-interference design, unreasonable device selection, improper protection and imperfect self-inspection leads to easy damage; SLD light source is a weak link in the reliability of acquisition unit. In the process of production, the service life of SLD light source is easily affected by electrostatic damage; During use of the product, the heat of SLD light source causes the temperature rise and reduces the service life; The PCB production technology of acquisition unit is deficient.
Defect type: Device quality problem; design problem; quality control problem; manufacturing process problem; installation problem.
Solutions: Strengthen the quality control of acquisition unit, select high-quality components, strengthen in-factory testing, optimize device management and real-time monitoring; Strengthen the low-power design and heat dissipation measures of the acquisition unit, and fully consider the temperature and humidity requirements of the operation site, the acquisition unit should be configured in a ventilated environment to avoid direct sunlight; In the process of packaging, transportation, welding, assembly, testing and replacement of SLD light source, electrostatic protection measures should be taken; Besides temperature control measures for the SLD light source, materials with high thermal conductivity are selected to increase the heat dissipation efficiency of light source and avoid heat accumulation; Improve the board design and process quality level; Strengthen testing, improve testing standards.

3.2.2. Air leakage of the transformer body
Defect cause: When the all-fiber ECT is integrated with DCB, the adhesive seal of connecting flange is poor.
Defect type: Manufacturing process problem.
Solutions: In the manufacturing process, the adhesive sealing process at the connecting flange should be improved; Intensify sealing inspection after product assembly.

3.2.3. Damage of optical fiber in optical fiber sensing ring
Defect cause: The sensing optical fiber is damaged by pulling and twisting forces during installation process.
Defect type: Installation problem.
Solutions: Standardize the installation process, and strengthen the protection of optical fiber on the project site.

3.2.4. Loss of optical fiber loop increases
Defect cause: The optical sending module is connected with the communication terminal by optical fiber jumper wire, when the optical fiber splice is loose, it is easy to be polluted by the dust, which leads to the loss increase and causes the communication error.
Defect type: Installation problem.
Solutions: Standardize the installation specifications, strengthen the cleaning treatment of optical fiber jumper and optical transmission port, to avoid dust pollution.

In summary, the defects of passive all-fiber ECT are mainly concentrated in the acquisition unit. The defects are closely related to the technical level, production process and quality control of the manufacturer. Acquisition unit components reliability is still difficult problems. To improve the reliability of passive all-fiber ECT, it is necessary to continuously strengthen the electrostatic protection and temperature control measures of SLD light source, and continue to strengthen selection and quality control of SLD light source, AD conversion module and other devices.

4. Conclusion
From the analysis of defects, the defects of active ECT are mainly concentrated in the acquisition unit and energy supply system, and the defects are closely related to the technical level, production process and quality control of the manufacturer. Acquisition unit components reliability, acquisition unit EMC design and laser power module reliability are still difficult problems. The defects of passive all-fiber ECT are mainly concentrated in the acquisition unit. The defects are closely related to the technical level, production process and quality control of the manufacturer. Acquisition unit components reliability is still difficult problems.

Different from the electromagnetic transformer, the electronic transformer belongs to the primary and secondary fusion equipment, and its defect rate is closely related to the reliability of electronic components. Therefore, redundancy design and modular operation and maintenance can be adopted to improve the reliability. Manufacturers should continue to increase technical input, optimize product design, select high-quality chips and strengthen screening, strengthen internal quality and process control, standardize on-site installation, operation and maintenance to reduce equipment defect rate.

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