Development and application of HVDC Cable polarization/depolarization current detecting instrument

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Abstract. In order to test the insulation state of 6kV XLPE cable reliably, the system design and related test work are carried out in this paper. High voltage excitation source, weak current test module, data acquisition system, communication, power supply and other hardware design work are described. The control of high voltage signal, switching of measurement mode, data acquisition of current and software design of man-machine interface are introduced. Finally, the designed test instrument is presented, and the field test results show that the home-made polarization and depolarization current (PDC) instrument can be used for testing, and the overall test performance is relatively good.

1. Introduction
The insulated cable has the advantages of high working temperature, large transmission power, light weight and simple installation [1-3]. It can effectively utilize the original transmission line corridor, improve the utilization rate of existing lines, and solve the problem of insufficient power of urban power grid to the maximum extent [4,5]. But as the increasing of cable quantity, the ascension of voltage grade and the extension of running time, before laying of cross-linked polyethylene, the ageing of the cable fault is frequent, resulting in the insulation failure, the regional power grid outage in serious cases, inconveniences to production and life, and major economic losses and casualties [6-8].

There are many methods to detect the insulation aging of XLPE cables, including insulation resistance method, dielectric loss tangent value (tanδ) method, partial discharge method, dc component method and space charge method [9-12].

At present, the research on polarization-depolarization current method at home and abroad mostly remains in the theoretical research and modeling and simulation stage, and there is few self-made detection equipment, and at the same time, there is a lack of field application and detailed experimental data comparison, which seriously affects its promotion progress and breadth in the industry.

In order to evaluate the insulation status of DC cable better, the design of the system and the related test work are carried out in this paper. The hardware design flow of high voltage excitation source, weak current test module, data acquisition system, communication and power supply are explained respectively. High voltage signal control, measurement mode switching, current data acquisition and man-machine interface software design are introduced. Finally, the designed test instrument is given.
2. Principle of polarization depolarization and overall design scheme

2.1. Principle of polarization depolarization test
Polarization-depolarizing test principle is shown in Figure 1. The DC voltage is applied to upper end of the test sample, as excitation source, the bottom ground, closed switch S1, S2 disconnect, and t0 duration, in the process of the sample under the action of inner and outer applied electric field can produce different kinds of polarization, at this time through the galvanometer to record the current size, the current is determined by the medium conductance and various polarization current combined. Then disconnect S1, close S2, and continue for t0. At this time, remove the dc voltage, and the test sample is in the short-circuit state. The polarization current includes leakage current, absorption current and instantaneous current. In contrast to the current generated by the polarization process, the depolarization process produces a discharge current flowing in the opposite direction through the galvanometer. It is generally believed that the longer the polarization-depolarization-time, the more complete the two processes. The change relation of the current curve with time is recorded, that is, the polarization depolarization current curve. The typical polarization depolarization current curve is shown in Figure 2.

![Figure 1. Schematic diagram of PDC test](image1)

![Figure 2. Current curve measured by cable PDC method](image2)

2.2. Total design scheme
The overall scheme of the system designed in this paper is as follows. The polarization depolarization testing system mainly includes voltage excitation, current measurement, data acquisition and other modules. During the test, dc voltage excitation is applied to both ends of the insulating medium, and the leakage current is converted into voltage signal through the current measurement module at the end. The signal is subsequently collected and transmitted to the data analysis unit through the data acquisition card. The dc excitation source designed in this paper can achieve the voltage output of 0~3kV, and the module can be controlled and adjusted by the low-voltage signal of 0~10V at the front end. PDC is mainly a weak current signal, but in fact, the current signal cannot be directly collected, so it is necessary to convert the current signal into a voltage signal, so as to achieve the signal acquisition. Therefore, the microcurrent test module realizes the current measurement at pA~mA level. The data acquisition module completes the acquisition of the amplitude of the current to be measured. The data acquisition card module should have a high sampling rate. The relay switching module is used to switch the polarization and depolarization current test modes, and ensure that the instrument is only in one test mode during the test, so the relay module needs to have the interlock function to ensure the safety of the instrument and the tester.
3. Hardware module design

3.1. Data acquisition module design
This paper adopts data acquisition card to realize data acquisition. The selected data acquisition card should meet the following requirements:

1) Data acquisition card adopts PCI bus protocol.
2) Higher sampling number.
3) The sampling voltage reaches above 5V, and the bipolar sampling is realized.
4) Double-channel synchronous sampling is required.
5) The analog voltage output is between 0 and 10V.
6) The analog output bits have high accuracy.

Considering the performance indexes required by the above design, this paper selects the EM9636M/AA acquisition module for data sampling.

3.2. DC high voltage module design
The PDC test instrument can output a maximum voltage of 3kV. Meanwhile, the output voltage of the power supply should meet any range from 0 to 3kV and can be selected. Therefore, this paper controls the signal output of the high voltage source by adjusting the low voltage source. The scheme is realized by the following working principle: first, the data acquisition card generates the dc voltage up to 10V, and can be freely regulated from 0V to 10V. Through the module's 0~10V voltage control rear end 0~3kV high voltage output, can achieve 100 times of signal amplification. The small signal at the front can make full use of the signal amplification analog output function of the data acquisition card, so as to reduce the improvement requirements on the low-voltage signal source in the design process and make the instrument as small as possible.

3.3. Weak current module design
The weak current module designed in this paper can realize pA-mA level current measurement. The weak current amplification module is the key point in this design and also a very big difficulty. The design goal should meet the following five requirements:

1) Range: adjustable within pA ~ mA range;
2) Test band: DC ~ 10kHz;
3) With less current noise, more accurate testing can be achieved;
4) Low ripple system;
5) With a small volume, it is convenient to realize the miniaturization of the instrument.

In order to realize the signal test of large current, this paper selects the weak current module HB-873 to build the system. The HB-873 schematic block diagram is shown in Figure 3. The module consists of the following parts: the zeroing circuit, the I-V conversion circuit, the dc/ac selection circuit, the gain control circuit, the low pass filter, the amplifier, the output stage and the power supply. The current Ii to be amplified is input from the current input end, and through the high-sensitivity I-V transformation circuit, the current signal is converted into a voltage signal, which is sent to the amplifier for signal amplification, and the output signal is then transmitted to the low-pass filter for noise or interference signal filtering. Finally, the signal is sent to the output stage for output, and the output voltage Vo is finally obtained.
4. Software module design

4.1. Current data acquisition and processing software control design

The test results of the instrument are mainly collected through the data acquisition system, which is mainly composed of the following four parts: sampling length setting, sampling frequency setting, data processing and data storage. The main flow chart of this process is shown in Figure 4.

![Flow chart of data acquisition](image)

4.2. Man-machine interface design

The software interface of polarization-depolarized current measurement is shown in Figure 5, which can reasonably set communication parameters, discharge voltage, amplification factor and filtering parameters. The output results of polarization curve, insulation resistance, polarization index and absorption ratio are displayed in real time.

![Software interface](image)
5. Laboratory and field test results

The self-made PDC experiment platform includes high-voltage power supply, acquisition module, relay, micro-current measurement module, etc. The Lab VIEW program is programmed on the IPC to realize the PDC experiment function. Its flow design mainly includes polarization current measurement, depolarization current measurement and end measurement. The physical diagram of the experimental platform is shown in Figure 6.

In this paper, the test is conducted on the sample sections of the three-core XLPE cables of 6kV and 35kV about 20cm in the laboratory. Before the test, the cable needs to be pretreated: part of the cable insulation layer is stripped to expose the conductor as the connection end of high voltage, and the outer semi-conductive layer of the cable is used as the measuring end. Test conditions adopted: voltage 0-3kv, test time 10000s, test results are shown in Figure 7.

It can be seen from Figure 7 that, for the test of 20cm cable in the laboratory, the polarization current fluctuates in the first half of the test, which may be disturbed to some extent. In the process of depolarization test, the overall curve is good, and there are small burrs at the end of the test, which is obviously caused by interference. On the whole, the polarization and depolarization currents have
obvious attenuation curves, which indicate that the self-made instrument can test the polarization/depolarization currents well.

Two power supply cables of a petrochemical enterprise in Tianjin were tested with the polarization depolarization detector developed by ourselves. The field equipment test wiring diagram is shown in Figure 8. The test results for the two cables are shown in Figure 9.

![Field wiring diagram](image)

Figure 8. Field wiring diagram

From Figure 9b and 9d, it can be seen that the polarization current curves of the sea water pump and the power supply cable of the low-voltage pump both show typical attenuation curves, indicating that the self-made instrument can perform a good polarization/depolarization current test. When stable stage to calculate the sea water pump with low pressure pump power cable insulation resistance as shown in Figure 9 a and 9 c, resistance stability in 8000 mΩ and 6000 mΩ. Using high pressure shake table measuring the insulation resistance of the same location, value is about 7850 mΩ and 5800 mΩ, and test results in the development of the instrument, the accuracy of the detection system is verified.

6. Conclusion
This chapter completes the development of modular polarization/depolarization current measuring instrument, mainly including the following:
(1) The design of polarization/depolarization current hardware module. Through the analog output function of the data acquisition card, the controllable output of the dc high voltage source from 0 to 3kV is realized. By using the method of I-V transformation, the test of weak current module is completed. As can be seen from the test results, this micro-current test module meets the test requirements of pA–mA level current. According to the actual requirements of operation and maintenance work, the maximum test time can be set up to 10000s.

(2) The software control design of polarization/depolarization current measuring instrument is completed. By combining with the hardware equipment, the flow of analog gain control, data acquisition and I/O communication of PDC test equipment is designed, and on this basis, the overall flow design of PDC test mode is completed. High voltage signal control, test mode switching control, current data acquisition and program design of man-machine interaction interface are realized. On the interactive interface, 0~10V analog signal can control the output of 0~3kV voltage signal, and the user can set the polarization/depolarization time, sampling frequency and other functions.

(3) The relevant testing work is carried out for the polarization/depolarization current measuring instrument designed in the paper. The cable section and field cables in the laboratory were tested. The self-made instrument could measure pA level current in the 6kV and 35kV cross-linked polyethylene cables of 20cm in the test laboratory. The field test results showed that the self-made PDC instrument could also be tested, and the overall test effect was relatively good.

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