Abstract. It is usually difficult to detect a small current signal in a high-pressure environment with strong electromagnetic interference. The paper introduces a high-voltage electrical equipment that is used to measure the small current. The system consists of three parts including the DC high voltage generator, data acquisition modules and PC data display section. The experimental results show that the device can acquire weak current signal effectively. Data acquisition module can communicate with the PC software with Ethernet, and the users can store, query the data through a database easily.

1. Introduction

In recent years, with China's sustaining and rapid economic growth, electricity demand is increasing and the voltage level of transmission line is grading, which has put forward higher performance requirements for the insulator used in transmission line. Under the promotion of national policy, Dalian Insulator Group focuses on the manufacturing industry of insulators, and the annual output has reached 150,000 pieces. Especially the suspension porcelain insulator used in the DC transmission line plays a key role in several 500 kV EHV transmission engineering projects. There are more than 1,000,000 pieces of XWP-70, XWP-160 and XWP-210 with different contaminated levels running on these 500 kV transmission lines in China, which keep good running records and guarantee the safe and reliable operation of transmission lines [1].

At the same time, Dalian Insulator Group and Dalian University of Technology carried out the research on the technology of detecting the insulator. Based on the enterprise’s requirement for the measurement technique, it’s necessary to conduct typical tests and sampling tests to ensure the products’ eligibility when the products are dispatched from factory. But currently when measuring the insulation resistance and volume current, enterprises are facing some problems including poor and obsolete equipments, too large leakage current when the element is exposed in the air, and very backward and poor accuracy of the artificial test method.

This paper designs an insulator leakage current measurement system based on PLC in order to realize the intelligent, accurate and efficient inspection work and solve problems for the enterprises.

2. The overall design of the system

The system mainly consists of three parts including a DC high voltage generator, a data acquisition module and a control PC. The DC high voltage generator is responsible for providing DC high voltage;
data acquisition module is responsible for collecting and processing data and communicating with the host computer; and control PC is responsible for data display and saving the queries.

This system uses PEC8000 data acquisition module to realize the measurement of weak leakage current of insulator. The overall system structure is shown in figure 1.

Taking the insulation resistance of XP-70 insulator as an example, the experimental process consists of three steps. In the first step, the test system was built as shown in figure 1 and the insulator was put in the artificial high voltage chamber (constant temperature). In the second step, the temperature of incubator was maintained at 60 °C for 2 h in order to avoid the influence of humidity. In the third step, controlling the DC high voltage generator to output negative high voltage to insulator, the voltage was boosted to 15 kV and kept at 15 min to charge the capacitor stably. Then, data acquisition module will process signals, establish communication with host computer and measure the weak current using the software. The software can realize the intelligent management for the measured data.

3. The design of the hardware for the system

3.1. High voltage DC generator

ZGF-200 high voltage DC generator, which is developed by the Special Power Plant in Dalian University of technology, is used to provide the high voltage. This power supply uses containerized
integration technology for sealing well and avoiding of dust and moist. Voltage is output from the embedded type electrode and it can be adjusted continuously with small pulsating factor, small leakage current and high testing precision. In addition, the power supply has a protection measure for overload voltage and current, which is suitable for enterprise field test.

The main principle diagram is shown as in figure 4.

![Figure 4. Schematic diagram of the DC supply.](image)

As shown in figure 4, the input is 220 V AC, and after the conversion of the self-coupling voltage regulator T1, 0~70 kV voltage is output. Then, the AC voltage is converted to DC voltage and is amplified three times after three times rectifier circuit. The V0 point outputs negative polarity DC high voltage ranging 0 ~ 200 kV. It can greatly reduce the volume of the power using this kind of rectifier circuit. And output voltage pulsation can be improved by the different size of the capacitance group.

3.2. The design of data acquisition module

The system mainly uses the PLC to collect data for processing. Weak signal will be preprocessed by prefilter amplifier. Generally, the most important thing for the amplification is to select an appropriate amplifier which has a slight bias current. If amplification is for nA level of current signal, it must choose pA level bias current of the op-amp. This system mainly aims at the insulator leakage current measurements. Under a few kilo-volts high voltage, insulator volume current changes from dozens to hundreds of nA with the change of temperature and humidity.

![Figure 5. I-V Conversion circuit.](image)

In the design of sampling amplifier, I-V conversion circuit with good linearity performance is selected. Burr Brown Company OPA128 is chosen for the op-amp, the bias current is not more than 75
fA, and the offset voltage is 500 μV. To reduce the noise interference and op-amp load, usually output voltage should be two times or more compared with the input voltage, but if the output voltage is too high, feedback resistance \( R_f \) must be increased and op-amp performance requirements need to be increased at the same time. So it will be suitable for the design of the input voltage range form 50~100 mV. From the formula \( V_O = -I_S R_f \), \( R_f \) should be 100 MΩ when input current is nA range. But it can easily produce resistance thermal noise current and increase the distributed capacitance once the \( R_f \) is large enough. This system design uses the \( T \) resistance feedback network to improve resistance noise, as shown in figure 5.

There is some burr due to the noise interference after amplification. In order to filter out the interference, the system used a 20 Hz second order passive low pass filter. The effective signal is provided for the PLC after being filtered.

PLC module chose PEC8000 industrial Ethernet programmable controller, with 32-bit LPC2378 microprocessor as the core, with one 10 m/100 m industrial Ethernet communication interface, two RS485 communication interface, support MB + high-speed bus, eight digital input (support 4 top 50 kHz high-speed input), eight digital output (support 2 highest frequency 50 kHz high speed output), six analogue input, and two analogue output [2].

As shown in figure 6, in the PEC8000, DI0 - DI3 for ordinary switch input, DI4 - DI7 for four high speed switch input, A10 - A15 for six analog input signals, can input thermocouple/thermal resistance/standard current/standard voltage signal. There is a light coupling isolation between physical input and output between LPC2378. And LPC2378 built-in the Ethernet MAC layer, by connecting the physical DP83848 chip, after level transformation, can realize Ethernet communication function. DQ0-DQ7 is for switch output, AQ0 and AQ1 are for analogue output [3].

In this system, the analog current signal after the preamplifier is sent into the interface circuit, then after AD converter ICL7135 realized the analog to digital conversion, photoelectric isolation, and then LPC2378 input port is connected. That means the input signal needs sampling, amplification, filtering, modulus conversion and photoelectric isolation before sending into the CPU input port. PEC8000’s input code value range is 0 ~ 10000 after analogue-to-digital converting. This paper’s design
according to different size of the current signal use different analogue input terminals, corresponding
to different code value range. When the input current range is 0 ~ 1000 nA, code value accuracy is 10
yards/nA; when the input current range is 0 ~ 200 uA, code value accuracy is 50 yards/uA. Current
signal after internal processing is sent to DP83848 Ethernet chip, and then can be connected to
computer through the twisted pair.

4. The design of system software

4.1. PLC module programming

PEC8000 programming based on the IEC61131 standard, the matched programming software provides
a functional block diagram language edit mode. The controller will contact up program and physical
input/output together, through the logic procedures to complete the corresponding control. The PLC
config software have given many algorithms of function block, such as logic operation, compare
instruction, timer, counter, etc., using the function block, the user can composite module freely and
realize complex algorithm.

The main program block diagram of the system is shown in figure 7. It should obtain input operator
EN firstly, if EN is 0, don't allow the function block execution, then will assign ENO value 0, if not,
allow the function block executive, then read input parameter, according to the function block
algorithm to carry on the calculation, and the calculated results will be written to output parameters,
and will assign ENO value 1, meaning that it can allow the output.

![Figure 7. Main function chart of the system.](image)

4.2. The design of interactive interface of the host computer

This system adopts Visual Basic6.0 to design the user measurement interface of the host computer.
VB is a kind of object-oriented, visual and event-driven programming language, which could write out
a user-friendly operator interface. Before measurement, user can set external environment variables,
including the type of electrical equipment and temperature. User can also set the parameters in
measurement, such as the sampling time, number of samples, accuracy and channel selection etc.
Measurement interface is shown in figure 8.

![Figure 8. Measurement interface.](image)
4.3. The design of database.
In order to be convenient for the operator to record, analyze and query the measurement data, this system adds on the function of database management, which can use SQL Server to build relational data table and link the characteristics amount of the sample models, temperature, voltage, current and test time etc. Then the application of host computer can use ADODB control in VB to operate the database [4].

4.4. Communication between PLC and host computer
The communication protocol used in this system is Ethernet MODBUS protocol. Compared with traditional Ethernet communication protocol, MODBUS protocol extends new packet header in the data link layer, which can identify the data unit using this protocol and is very suitable for industrial control. PEC8000 module connects to the computer via twisted pair, the communication port is 11000 by default and the transport layer uses the UDP mode to transmission packets. Host computer configures the properties of the relevant agreements and triggers the events via the Winsock control of VB.

5. Conclusion
The measurement system using Ethernet can solve the difficulties of intelligence and accuracy during the test of insulator leakage current in this paper. This system has been in use since 2010 and keeps stable and efficient until now. In addition, this system also plays an important role during the measurement of actual voltage and current in high-voltage electrical equipment.
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