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Application of extension neural network algorithm and chaos synchronization detection method to partial discharge diagnosis of power capacitor

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ABSTRACT

The power capacitor is an important equipment of a power system, which must run in a high-temperature and high-voltage environment for a long time, in order to maintain the stability of system. Hence, the failure rate of the power capacitor increases over time. Conventional capacitor testing methods mostly require multiple sensors and signal parameters, which increase system cost and complexity. This study attempted to propose a novel method for capacitor fault recognition. It developed a fault diagnosis system for power capacitor by employing the extension neural network (ENN) algorithm and the chaos synchronization detection method. In terms of signal acquisition, partial discharge was measured by hardware circuits, such as high-frequency current transformer (HFCT), high-pass filter, noninverting amplifier circuit, and high frequency oscillography. The ENN and the chaos method were integrated with hardware circuits to develop a human-machine interface fault diagnosis system designed with LabVIEW. The proposed method was also compared with extension method and artificial neural network algorithm. According to the results, the ENN has the best recognition result, and the huge data could be reduced greatly by the data pre-processing of the chaos synchronization detection method. Any subtle changes in the power capacitor discharge signal could be detected effectively, thus achieving an accurate operating state of the power capacitor.

1. Introduction

People's quality of life and economic development often rely on safe and stable operation of power systems. However, as power equipment operate in a high- temperature, high-tension, and high-load state for extended periods, the equipment is likely to wear out faster. At present, the Taiwan Power Company conducts periodic inspections for power system maintenance. While the number of substations and equipment has increased significantly in recent years, the periods between inspections are too long. This fails to meet the requirements for the safe operation of power equipment. If power equipment faults can be predicted in order to replace and repair equipment, the economic losses resulting from equipment shutdown will be greatly reduced. Therefore, the on-line condition monitoring and fault diagnosis of power capacitors are the key points discussed in this study.

Many recent studies have been conducted on capacitors diagnosis based on partial discharge performance [1–3]. Ref. [1] proposed a fusion method which based on wavelet threshold denoising and mathematical morphology alternate mixing filter for extracting PD signal can monitor the insulation performance effectively. Ref. [2] described a virtual instrumentation system developed for the evaluation of high voltage power capacitor through capacitance monitoring and acoustic PD signals detection. Ref. [3] introduced a protection algorithm based on ratio and angular difference between phase currents and unbalance currents to detect internal failures for large capacitor. Besides mounting a number of sensors to capture the required electrical signals, these studies have to extract many eigenvalue data for effective analysis, thus increasing the system construction costs and complexity. In addition, in terms of the present research on the power capacitor fault diagnosis, few studies have integrated relevant hardware circuits with a recognition algorithm to develop a human-machine system.

The fault types include wetting, insulation aging, support discharge, insulating oil spills, connection strap dropouts, and immersion defectiveness [4–6]. This study focused on three common fault types, including metal case swelling, metal sleeve wear, and metal sleeve impurity. First, a defective power capacitor was created, and a high voltage step-up transformer was used for an applied voltage test [7]. When the insulation of the capacitor was defective or aged, the

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discharge pulse damaged the insulating layer inside the capacitor, leading to penetrative destruction. Afterwards, the power capacitor-to-ground partial discharge signal was measured by a sensor [8]. The fault features were extracted by the chaos synchronization analysis method. Finally, the capacitor feature values were analysed by ENN for accurate fault category identification. This series of tests, including capacitor partial discharge, signal measurement and interception, data analysis, and fault type diagnosis, were demonstrated by the self-developed LabVIEW human-machine interface program.

2. Power capacitor partial discharge test

In the measurement of the partial discharge signal (pulse signal) of a power capacitor, the extracted discharge signal has a long period and high frequency, and the data volume is huge. In addition, as there is too much electrical noise interference during the test, it is difficult to identify the signal of the partial discharge. In order to effectively extract the high frequency signal from a partial discharge signal, the low frequency signal and noise must be filtered off using a high-pass filter [9]. The research process in this study is comprised of power capacitor defect construction, an on-line measurement test, the high-pass filter design and the noninverting amplifier design, as described below.

2.1. Power capacitor defect construction

This study used three defective power capacitors of the same model as the partial discharge measurement test subjects. The specifications are shown in Table 1. The first fault to be tested was metal case swelling, which is an eliminated product provided by Taiwan's electricity supplier. According to the test, the insulating oil in the capacitor became oxidized, the capacitor was damaged, and the casing swelled, as shown in Fig. 1. The second fault was metal sleeve wear, as caused by construction defects, in which the paint on the metal sleeve under the insulator became worn. The sleeve partially contacted the air, thus, generating discharge, as shown in Fig. 2. The third fault was metal sleeve impurity. During the power capacitor manufacturing process, if there were metallics left in the metal sleeve, the sleeve of the power capacitor generated a nonuniform discharge, as shown in Fig. 3.

Fig. 1. Metal case swelling.

2.2. On-line measurement test

The main purpose of the on-line measurement test is to test the state of the power capacitor. This study used an AC withstand voltage test on the insulating property of the power capacitor. First, the step-up transformer applied 8 kV voltage to the single-phase terminal of the power capacitor. The partial discharge signal was measured by a high-frequency current transformer (HFCT) and the self-made detection circuit. The HFCT using ring type of Ni-Zn ferrite core was constructed in this study. Eight turns of enameled copper wire were mound over the ring core. The frequency bandwidth of the HFCT at 50 Ω was designed in the range of 6 MHz–50 MHz. Generally, ferrites were ferromagnetic ceramic materials with high permittivity, resistivity and high permeability in high frequency applications [10,11]. Then the analog signal was transported from the oscillograph and the data acquisition (DAQ) equipment to the server-side of the LabVIEW human-machine interface system for analysis, as shown in Fig. 4 [12]. When the insulation of the capacitor was boosted to the critical point, the discharge pulse slowly broke down the insulating layer, leading to damage; meanwhile, the pulse current flows to the ground terminal by means of its transport property, and couples to the HFCT sensor.

Table 1
The Specifications of Power Capacitor.

Items	Low Voltage Power Capacitor
Rated Capacity	70 kVAR
Capacitance	1286 μF
Phase Number	Three
Frequency	60 Hz
Rated Voltage	380 V
Rated Current	106 A

Fig. 2. Metal sleeve wear.

This series of tests, including power capacitor partial discharge, signal measurement and capture, data analysis, and fault type diagnosis, was demonstrated by the self-developed human-machine interface system as shown in Fig. 24.

2.3. Partial discharge detection circuit

The detection circuit in Fig. 4 is a self-made partial discharge signal detection circuit, which includes a high-pass filter and a noninverting