The Software Design of Intelligent Diagnosis System for Partial Discharge Fault of GIS

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***Abstract*—The correct identification of GIS partial discharge type is essential for assessing the insulation status of GIS and developing a reasonable maintenance strategy. After the analysis of the intelligent diagnosis system design, the software architecture of host and remote computer is given by this article. Site host computer completes the data preprocessing and the remote host computer completes the function of real-time observation, data storage and inquiry, spectrum analysis and pattern recognition. The test shows that the software can complete the intelligent recognition of partial discharge.**

Keywords- Gas insulated switchgear, Partial discharge, Pattern Recognition, Neural network

I. INTRODUCTION

As a high-voltage switch, gas-insulated substation (GIS) is widely used in power system and enterprise users. The most common characteristic in GIS electrical failure is partial discharge before insulation breakdown. So, correct identification of partial discharge fault type is crucial to assess the condition of GIS insulation and formulate a reasonable maintenance strategy. Identification of discharge type is also the problem of pattern recognition. Common method is making artificial neural network as a pattern classifier to identify, in the analytical mode of phase [1,2].

This paper designs software of intelligent diagnosis system for partial discharge based on this principle. Introduces architecture of software and functions in detail, and focuses on the process and implement method of intelligent recognition.

II. DESIGN OF INTELLIGENT DIAGNOSIS SYSTEM FOR FAULT

As Figure.1, the structure of fault diagnosis system tells its rationale. When partial discharge occurs in GIS cavities, the ultrahigh frequency electromagnetic waves are stirring up. UHF sensors detect the waves, discharge pulse waveform output after detection, then discharge signal is real-time collected by high-speed data acquisition card, moreover it is phase synchronization between data acquisition and power frequency voltage. Site hosts preprocess the discharge data, transfer the data to the remote host through the cable. Remote hosts analyse discharge signal in the phase analytical mode, extract the characteristic parameters from spectra as the input of neural network classifier. Type of discharge fault is derived from the output of neural.

LabView provide a convenient, relaxed environment to the virtual instrument designers. As easily as building blocks, designers could set up a measuring system and construct their own instrument panel. Therefore, this paper develops software in LabView.

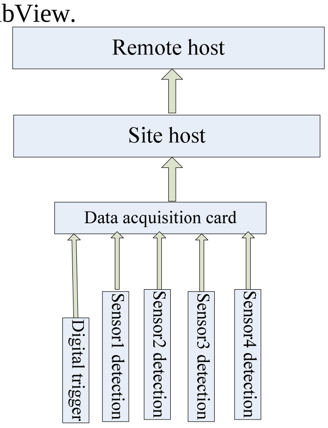


Figure 1. The system construction

III. SOFTWARE DESIGN OF SITE HOST

Program flow chart of site host is shown as Figure.2:

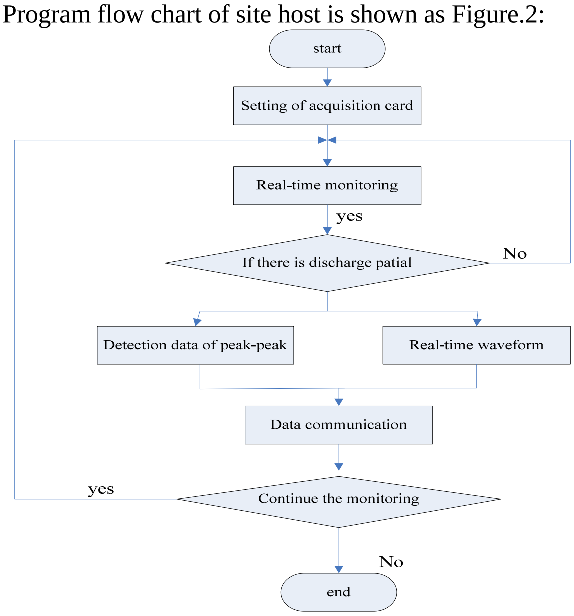


Figure 2. The program flow diagram of site computer

First, program must set the parameters of acquisition card, and then collect the demodulated signals from acquisition card. According to the online monitoring and setting of threshold voltage, judge the collected signal is noise or discharge signal. If there is partial discharge, data preprocessing will be carried out. The amplitude and phase information of discharge phase are extracted by the preprocessing, which is finished by the peak-to-peak detection module. And the amplitude and phase information of discharge phase could be got by peak-to-peak detection because data acquisition is synchronized with the external power supply voltage signal. After pretreatment, data and information of real-time discharge waveform are transferred through the cable to remote host for processing. The front panel of site host program is shown as Figure3, and power frequency voltage waveform and discharge pulse waveform are shown in it.

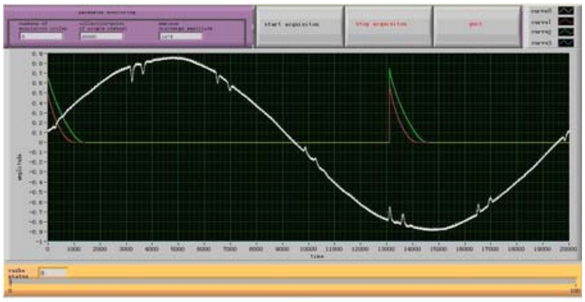


Figure 3. The front panel of site computer

IV. SOFTWARE DESIGN OF REMOTE HOST

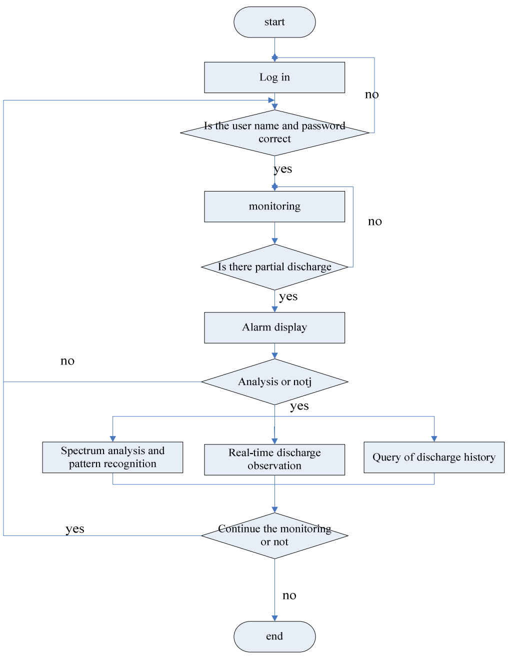


Figure 4. The program flow diagram of remote computer

Program flow chart of remote host is shown as Figure.4.

Remote host focus on the functions such as history inquires of discharge, real-time discharge monitoring, spectrum analysis and pattern recognition.

A. *Real-time observation of discharge*

Real-time observation of discharge is used for the observation effects as Figure.3 in the remote host. Due to the sample rate of acquisition card in the paper is 1MS/s, in every 100 frequency cycle of acquisition, there are 2M data sizes. And these data are not saved, real-time refresh is taken.

B. *Data storage and history inquire of discharge*

Data storage is used to keep a record of amplitude and phase of discharge and time information about discharge. In the LabView, there are two common ways to achieve the system data management: data base management system and file system. In this paper, we take a combination of file system management and data base management as the data management. Differences between the two kinds of memory contents are shown as Figure.5. The memory contents in text are used for spectrogram analysis. And contents in data bank are used for historical trend analysis of discharge.

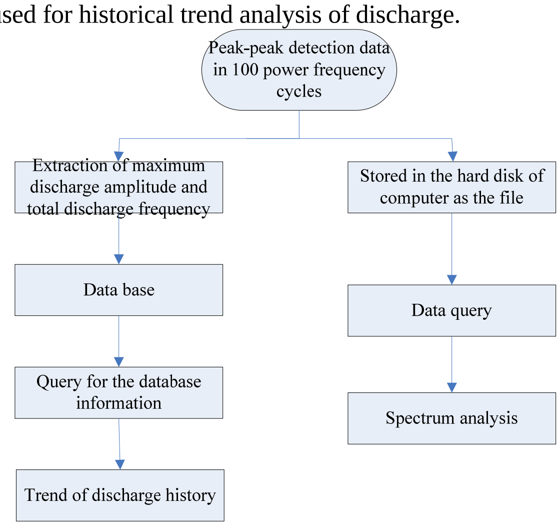


Figure 5. The data storage

Figure 6. The inquiry of discharge trend

Main tools to write database are SQL and LabSQL. SQL is used for query, modifying data and managing database. LabSQL is a free LabView database access tool, which supports multidatabase and cross-platform. The front panel is shown as Figure.6, which is the discharge trend inquiry through database inquiry.

C. Spectrum analysis and pattern recognition

The flow of spectrum analysis and pattern recognition is shown as Figure.7

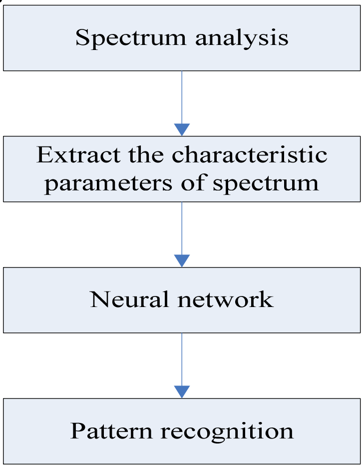
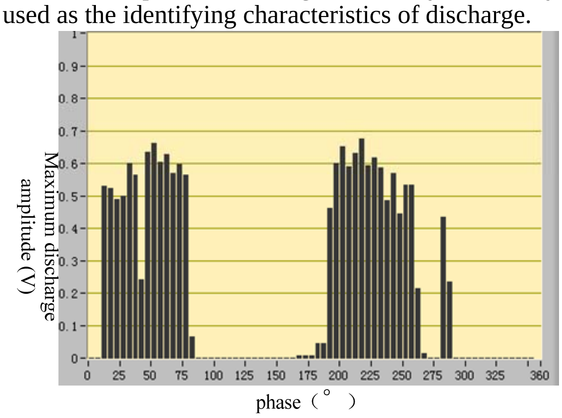


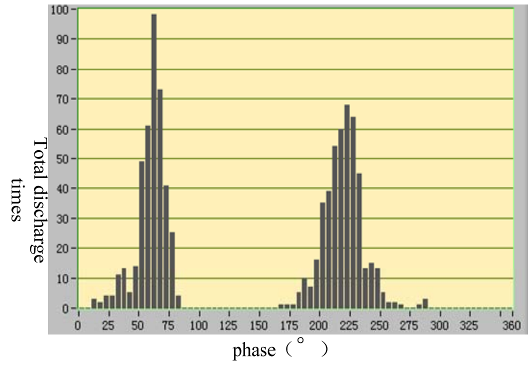
Figure 7. The flow of pattern recognition

1) Spectrum analysis

In this paper, we analyse the partial discharge in mode of phase analysis, then construct the two dimension spectra including $U-\varphi$ spectrum and $N-\varphi$ spectrum. $N-\varphi$ spectrum is the statistics of relation between maximum discharge amplitude and phase in 100 power frequency cycles. $N-\varphi$ spectrum is the statistics of discharge times for each phase section in 100 cycles. Due to them, the conclusion is more universal, and the width of phase window in spectrum analysis is 5 degree. Figure.8 shows the two-dimensional spectrum when discharge fault type is floating potential. From the experiment analysis, sharps of different kinds of discharge spectra are different, as well as the profile difference of positive and negative half cycle, so they can be used as the identifying characteristics of discharge.



(a) $U-\varphi$ spectrum



(b) $N-\varphi$ spectrum

Figure 8. The two-dimensional spectrum

2)extraction of the spectra characteristic parameter

This paper selects 6 features, which are used for the characterization to spectra shapes and differences of positive and negative half-cycle profile[3-5].

a) Skewness S_k *:*

Skewness is used for describing the skew about distribution of any shape in contrast to the normal distribution, that is:

$$S_k = \sum_{i=1}^{W} (x_i - \mu)^3 \cdot p_i \Delta x / \sigma^3 \tag{1}$$

In this formula, W means the number of phase window in one-half cycle; x_i means the phase of the i th phase window; Δx means the with of phase window; p_i, u and σ means the probability, value and standard deviation in the event of phase window i, when the spectra are regarded as probability density profile, meanwhile φ_i as the random variable.

$$p_i = y_i / \sum_{i=1}^{W} y_i \tag{2}$$

In this formula, y_i is the ordinate of spectrum, and represents discharge amplitude.

$$\mu = \sum_{i=1}^{W} p_i \varphi_i \tag{3}$$

$$\sigma = \sqrt{\sum_{i=1}^{W} p_i (\varphi_i - \mu)^2} \tag{4}$$

Skewness shows the information of right and left deflection about spectrum shape relative to normal distribution. S_k=0 means the shape of spectrum is bilateral symmetry; S_k >0 means the shape relative to the normal distribution is left skewed; S_k <0 means the shape relative to the normal distribution is right skewed.

b) Kurtosis K_u *:*

Kurtosis is used for describing the kurtosis about that distribution of any shape is in contrast to the shape of normal distribution. It is defined as:

$$K_u = [\sum_{i=1}^{W} (x-\mu)^4 p_i \Delta x / \sigma^4] - 3 \quad (5)$$

To a normal distribution, the kurtosis is K_u =0. If K_u >0, it means the profile of this spectrum is steeper than profile of normal distribution. And if the K_u <0, it means the profile of this spectrum is flatter than the one of normal distribution.

c) Cross correlation coefficient cc *:*

Cross correlation coefficient shows the similarity among shapes in the positive and negative half cycle of a spectrum. Its computational formula is:

$$cc = \frac{\sum_{i=1}^{W} u_i^+ u_i^- - (\sum_{i=1}^{W} u_i^+ \sum_{i=1}^{W} u_i^-)/W}{\sqrt{[\sum_{i=1}^{W} (u_i^+)^2 - (\sum_{i=1}^{W} u_i^+)^2/W][\sum_{i=1}^{W} (u_i^-)^2 - (\sum_{i=1}^{W} u_i^-)^2/W]}} \quad (6)$$

Here, u_i^+, u_i^- is the amplitude of discharge in phase window i , and superscript "+", "-" is corresponding to positive and negative half-cycle of spectrum. When the cross correlation coefficient $cc \approx 1$, it means the profiles of $U-\varphi$ spectrum in the positive and negative half cycle are similar. And when $cc \approx 0$, it means there is a big difference among the profiles.

d) Factor of discharge capacity Q *:*

Factor of discharge capacity Q shows the difference of discharge capacity between positive and negative half cycle of $U-\varphi$ spectrum. It is defined as the ratio of discharge capacity between positive and negative half cycle, that is:

$$Q = \frac{\sum_{i=1}^{W} n_i^- u_i^-}{\sum_{i=1}^{W} n_i^-} / \frac{\sum_{i=1}^{W} n_i^+ u_i^+}{\sum_{i=1}^{W} n_i^+} \quad (7)$$

In this formula, n_i^+, n_i^- is the repetition rate of discharge in phase window i, superscript "+", "-" is corresponding to the positive and negative half cycle of $U-\varphi$ spectrum.

e) Asymmetry of phase ϕ *:*

It shows the difference among starting phase of discharge in the positive and negative half cycle of $U-\varphi$ spectrum, that is:

$$\phi = \frac{\phi_{in}^-}{\phi_{in}^+} \quad (8)$$

In this formula, ϕ_{in}^+, ϕ_{in}^+ is the starting phase angle of discharge respectively in the positive and negative half cycle of $U-\varphi$ spectrum.

f) Amendatory cross correlation coefficient mcc *:*

It is used for evaluating the differences of discharge type in the positive and negative half cycle of $U-\varphi$ spectrum, defined as $mcc = Q\phi cc$.

As showed in Figure.9, for the extraction of characteristic parameter, program segment is written according to the formula above, in formula node of LabVIEW.

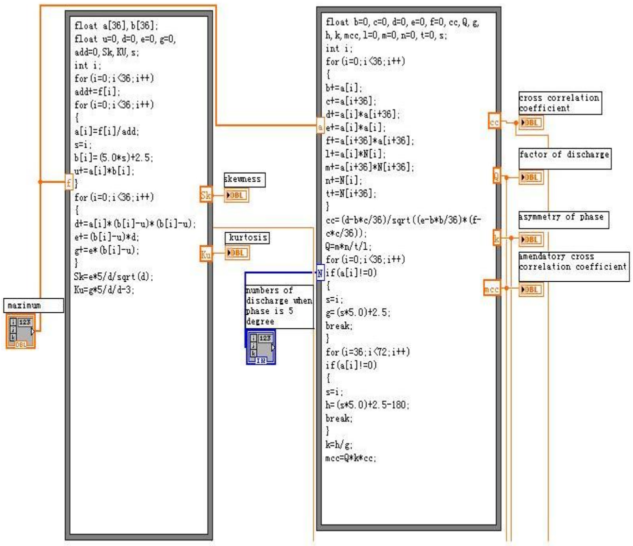


Figure 9. The extraction of characteristic parameter

3) Neural network training and LabView programming

Training of neural network is a very important process for the use of neural network. In this paper, the training is done under MATLAB Script node of LabView.

Figure.10 is the program chart of training.

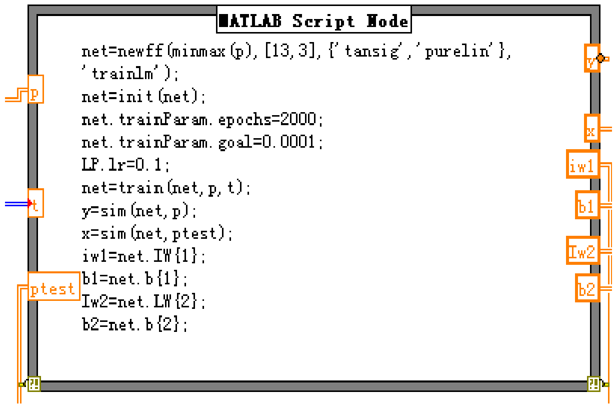


Figure 10. The training of neural network

In this program, p means the training sample; t means the target output; ptest means the test sample, is used for testing well-trained neural network, from its result, to make sure whether the training meets requirement. First use the newff function to build a new neural network, which is a BP neural network[6,7] , including 3 layers: input layer, hidden layer, output layer, and the training function of this neural network is trainlm. After training, we use the sim function to output result of training, and use the ptest sample to verify quality of training. In this paper, the samples from 3 types of discharge fault are used for training neural network.

After training, get the weight and bias for every layer of neural network. These data can be directly used for building an in-out mathematic relation for neural network to predict the type of new input corresponding to. Do not have to call MATLAB to train the neural network and output the result by sim function with MATLAB Script node, just need to package the VI from aforementioned trained neural network into child VI. When the weight of neural network is called for update, call the training.

The output mathematical expression of neural network is:

$$F = purelin(IW_2 * \tan sig(IW_1 + b_1) + b_2) \quad (9)$$

Make the 6 characteristic quantities from spectrum data as input for this neural network, and multiply them by the weight matrix IW_1, then add the bias b_1, make the result as input for transfer function of hidden layer: $f_1 = \tan sig(x)$ .And make the output of this function as input of input layer, the mathematical expression of $\tan sig$ is shown as:

$$\tan sig(x) = 2/(1+e^{-2x}) - 1 \quad (10)$$

There are 13 neurons in hidden layer, so there make the 13 outputs as input of output layer. As well, 13 inputs multiply by weight matrix and add the bias, the result above is input for the transfer function of output layer: $f_2 = pureline(x)$, and the function expression of $pureline$ is:

$$pureline(x) = x \quad (11)$$

Finally, make the output of 3 neurons from output layer as basis of pattern recognition. According to the above mathematical expression (9), build LAbView program like Figure.11. This program implements the prediction of neural network, and output after operation is used for discharge pattern recognition. Store the 3 outputs as arrays, determine the maximum value of them, then confirm type of discharge according to the index count of storage, make 0 as solid granules, 1 as floating potential, 2 as pinpoint discharge.

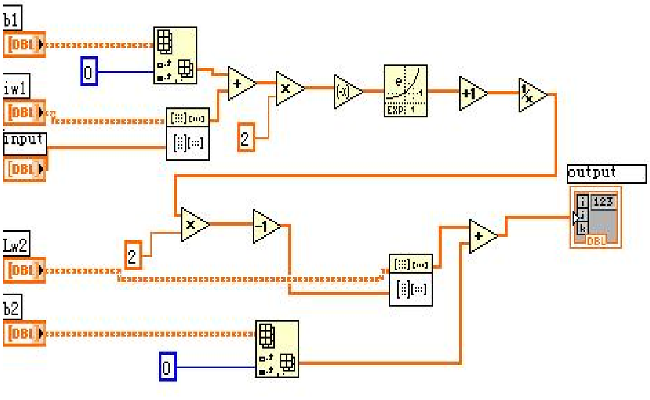


Figure 11. The neural network program based on LabVIEW

4)Results of the pattern recognition

Figure.12 is the front panel of intelligent recognition. Type to be recognized is floating potential, its spectrum analysis is shown as Figure.8. After the characteristic parameters are obtained by the program segment that shows as Figure.9, input them into the module corresponding to the Figure.11, we can get the result [-0.39986657, 1.4390078,-0.039629], and the maximum value of index number in array is corresponding to1. From them, the result of recognition is floating potential discharge, so the results of intelligent recognition are correct.

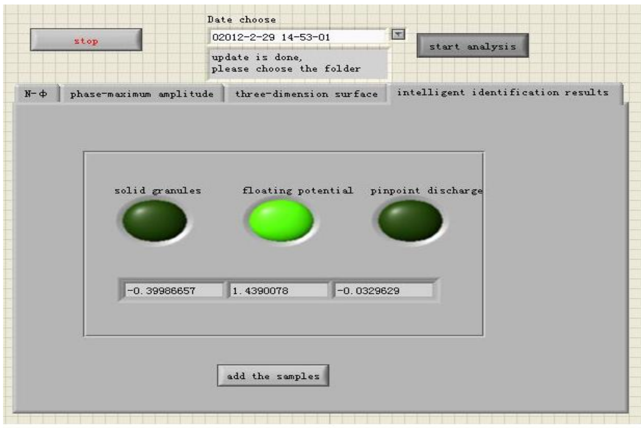


Figure 12. The front panel of intelligent recognition

V. CONCLUSION

This paper designs software of intelligent diagnosis system for partial discharge fault. Functions like waveform real-time display, storage and query analysis of database, intelligent neural network are in the software. And from the experimental verification, identification of the discharge type can be confirmed by this software.

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