Study on Degradation Detection for Faulty Insulator in Transformer Substation and Transmission Line based on UV-C Pulse

Wang Zhuoyuan*, Geng Yixiao, Zhao Xuejun, Yu Zhiqiang, Chen Cheng, Zhou Chen

State Grid Hubei Yichang Power Supply Company, Yichang 443000, China

Keywords: insulator; regression analysis; monitoring; UV-pulse; degradation

Abstract: This paper designs a new detecting device for transformer substation insulators based on "Solar Blind" UV pulse. Then it puts forward a multivariant nonlinear regression analysis method to find the mathematical expression between degree of faulty insulators and distance, UV pulse and environment humidity. Through the establishment of the faulty insulators test model, this paper ranks the faulty insulators levels in the form of a percentage. The experiment results show that this mathematical relation can be the criterion of faulty insulators judgment.

1. Introduction

Insulator is an important device for electronic power system and its insulating quality plays a key role in power transmission system and substation. The partial discharging phenomenon of insulator is the reflection of the degradation degree thus it's possible to know the degradation through monitoring the insulator's UV pulse so as to reduce the the fault in substation [1-3].

UV-C pulse's device detection is an on-line monitoring method and has good working distance, strong anti-interference and unaffected by the weather, which make it a hot research spot in this years. [4] What's more, the detecting device is very cheap, so it is economical and convenient to transport, UV-pulse detection is much more suitable for complicated phenomenon like detection in substation [5, 6].

To detect the insulator's degradation statement from distance and achieve the insulator on-line monitoring, this paper designs a faulty detecting device based on "Solar Blind" UV pulse for transformer substation insulators. Based on this device, the regression analysis is applied to get the accurate mathematical relationship to judge insulator's deterioration degree.

2. Detection principle of system

Insulator's surface electric field could be seen as uneven electric field when it is working, depending on the degree of intensity, it can be divided into corona discharge, spark discharge and arc discharge. Spark discharge and arc discharge release lights including visible light, however, corona discharge releasesultraviolet whose wavelengthless than 400nm. The sun's ray contains ultraviolet too, but the ultraviolet whose wavelength is less than 280nm is almost absorbed by the ozone, monitoring this wavelengths of ultraviolet light can ignore the sun's interfere. The section below 280nm iscalled the UV-C or sun's blind zone, UV-pulse is the method which detects UV-C wavelengths from insulators and counts the pulse then analyzes the statement of insulators [7,8].

Degradation of insulator will cause the distortion, at the same time ultraviolet light will be significantly enhanced. To insulators accepted to transmission lines, incepted electric field strength is E_c:

$$E_c(V/m) = 30.38m\delta^n(1+\frac{0.298}{\sqrt{r}})\times 10^5 \quad (1)$$

  DOI: 10.25236/iwass.2018.060

In above equation, δ is relative density in air; n is air intensity index; r is radiu of wire; m is surface roughness factor, always less than 1.

UV-pulse detection can distinguish working insulators and degradation insulators from distance and get the on-line information, but the strength of the insulator discharge related to environmental temperature and humidity, the detecting distance also influence the amount of UV-C pulse. Therefore, it's necessary to design a faulty detecting device based on "Solar Blind" UV pulse for transformer substation insulators, considering the related variable which influence the on-line monitoring of insulators and providing proof for degradation insulator's judgment.

3. System prototype engine structure

Fig.1 is the System Structure Diagram of UV-pulse detection device, its main function is detecting UV-C pulse and transforming light signal into electric pulse signal, then updating data to the principle computer.

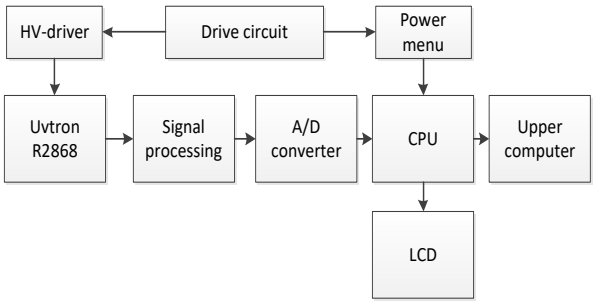

Fig.1 System structure diagram of UV pulse detection device

To detect the ultraviolet light and transform light signal into electric signal, the hardware circuit contains UV-C monitoring unit, signal processing, A/D convertor; working voltage of hardware circuit is 5V,but the UV-C monitoring Unit Uvtron R2868 needs 320V driving circuits, so it's needed to design special voltage transformation and stability circuits. According to the actual test, we choose PWM signal whose frequency is 350Hz and duty cycle is 0.5 as driving circuits for UV-C monitoring unit, this signal can help monitoring unit stop getting highly sensitive and less interfere, finally get the best test effect.

The device uses SCH11 digital sensor as humidity & temperature sensor, it can detect environmental humidity and temperature, providing accurate test data.

4. Insulator discharging experiment

Experiment is done in high voltage laboratory, environmental temperature is 25°, humidity set as 60%, 75%, 90%.

4.1 Division of the insulator degradation degree

Measuring insulation resistance is an effective way to find insulator's degradation. According to DL_T626_2005_Degradation of plate type insulator testing procedures, the insulation resistance of new insulator more than 500 MΩ, running insulator more than 300MΩ. Low value insulator's insulation resistancebetween 240MΩ and 300MΩ, zero value insulator's insulation resistance less than 240MΩ. The experiment selects FC70PL/146 insulator as the test sample, wherelow value insulators and zero value insulators are contained in sample. To ensure the accuracy of the data, the experiment get the average menu depending on multiple measurement from different distancs.

4.2 Experiment result

For this research the main measuring parameters is thedetect distance, environmental humidity and UV-C pulse. Output variable is the percentage of insulator degradation. Fig.2 is the experiment result in humidity 65%. From the result we can see that in same distance, the UV-C pulse rises with insulator's degradation; when environmental humidity increases, the amounts of insulator's UV pulse rises too; UV-C pulse is inversely proportional to detecting distance, this device can detect UV-C pulse from 10m,which can completely fulfill the need for insulator on-line monitoring in substation.

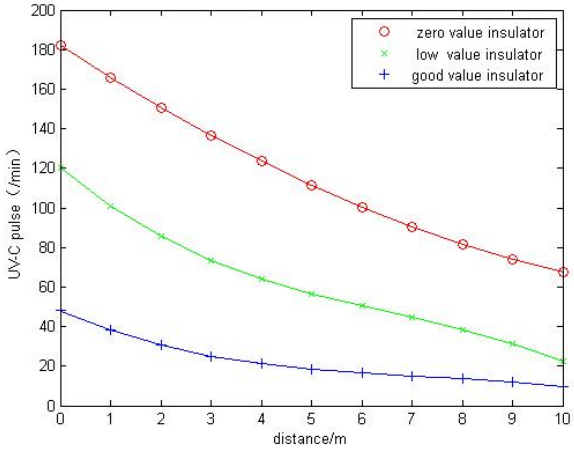

Fig.2 Experiment result for UV-C pulse detection in humidity 60%

5. Insulator discharging experiment

In order to determinethe specific formula of insulator's degradation degree, we usepartial least-squares regressive analysis based on rational function-difference splineinterpolation to build the model and get the judgment for percentage of the insulator degradation.

Process of regression analysis

Regression analysis is a statistical analysis method which can confirm relationship between variables. In research the input variable is distance, environmental humidity, UV-C pulse, the output variable is the degree of insulator degradation. Specifically you can design the judgement model of insulator degradation as nonlinear additive model

$$y = f_1(x_1) + f_2(x_2) + \ldots f_p(x_p) + \varepsilon \quad (2)$$

Result shows that relationship between output variable and input variables can be transformed into a ternary quadratic equation, the model is:

$$y = ax_1^2 + bx_2^2 + cx_3^2 + dx_1x_2 + ex_1x_3 + fx_2x_3 + gx_1 + hx_2 + ix_3 + L \quad (3)$$

In above equation, y is the percentage of insulator degradation, x_1 is distance, x_2 is humidity, x_3 is UV-C pulse, L is constant. According to the variance analysis, F value is 60.6,the significance level is0.00007(<0.005), it shows that the relationship between output and input variable is reliable.

To evaluate the accuracy of regression model, it's essential to take variance analysis and regression coefficient test, Here is the regression coefficient testmodel.the T value and test of significance prove that this model's fitting degree is very good.

$$\begin{aligned} y = {} & 4.396*10^{-5}x_1^{\,2} + 2.959*10^{-5}x_2^{\,2} + 3.599*10^{-4}x_3^{\,2} \\ & -2.321*10^{-4}x_1x_2 + 1.035*10^{-3}x_1x_3 + 1.228*10^{-4}x_2x_3 \\ & -0.122x_1 - 0.0204x_2 - 0.0483x_3 + 2.778 \end{aligned} \quad (4)$$

6. Conclusion

This paper designs a device that can detect the degree of insulator's degradation from distance and usesmathematical method to find relationship between input and output variables, finally builds the detecting model based on Nonlinear Regression Analysis. Experiment on control group shows that, this method can monitor insulators in substation on-line effectively. Insulators differ from materials and ies, more experimentsare needed to conclude the criterion which are suitable for all kinds of insulators, more accurate for insulator on-line monitoring.

References

[1] Gorur. R.S., Sivasubramaniyam. S. “Computation of defect-induced electric fields on outdoor high voltage ceramic and non-ceramic insulators”, Annual Report of Conference on Electrical Insulation and Dielectric Phenomena, Cancun, Mexico, Oct. 2002, pp. 319 –322.

[2] Dhalaan,S.M.A., Elhirbawy.M.A., “Simulation of voltagedistribution calculation methods over a string of suspensioninsulators”, Proceedings of the IEEE Power Engineering SocietyTransmission and Distribution Conference, Dallas, TX, USA, 7-12Sept. 2003, vol. 3, pp. 909 – 914.

[3] Lang, P.G., Allan, D.M., Zhou, Y. “Investigation of insulationdefects in transmission line disc insulators using remote detectiontechniques”. Proceedings of the 4th International Conference onProperties and Applications of Dielectric Materials. Brisbane, Aust.3-8 July 1994, pp.868 - 871.

[4] J. Ai, L. Jin, Y. Zhang, Z. Tian, C. Peng and W. Duan, "Detecting partial discharge of polluted insulators based on ultraviolet imaging," 2015 IEEE 11th International Conference on the Properties and Applications of Dielectric Materials (ICPADM), Sydney, NSW, 2015, pp. 456-459.

[5] F. c. Lv, H. Jin, S. h. Wang and H. d. Li, "Fault Diagnosis Based on Ultraviolet Imaging Method on Insulators," 2012 Second International Conference on Intelligent System Design and Engineering Application, Sanya, Hainan, 2012, pp. 1426-1429. doi: 10.1109/ISdea.2012.547

[6] Gorur. R.S., Sivasubramaniyam. S., “Computation of defect-inducedelectric fields on outdoor high voltage ceramic and non-ceramicinsulators”, Annual Report of Conference on Electrical Insulationand Dielectric Phenomena, Cancun, Mexico, Oct. 2002, pp. 319 –322.

[7] Eduardo.F, Sergio. C.O, Fernando.J, Renato.B.L, JF.M andE.Meneses-Pacheco, “Novel Sensor System for Leakage Current Detection on Insulator Strings of Overhead Transmission Lines”, IEEE Trans. Power Delivery, October 2006, vol.21, no.4, pp.2064-2070.

[8] Yangchun Cheng, Chengrong Li, “Online Detecting CompositeInsulators By Two Dimensions Electric Field Distribution”, Conference Record of the 2006 IEEE Internaltional Symposiun onElectrical Insulation 2006,pp.132-135.