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Property and ANN Simulating Model of Power Losses of ZnO Varistors

Se-Won Han, Jin-Liang He, and Han-Goo Cho

Abstract

ZnO varistors are widely used as surge arresters in power system based on their excellent nonlinearity. The property of power loss of ZnO varistors is related to the thermal stability and their life-spans of ZnO surge arresters. The power losses of ZnO varistors under different temperatures and applied voltages were measured, and the properties of power losses were analyzed. The Artificial Neural Network (ANN) was used to simulate the power losses properties of ZnO varistors which is an adaptive nonlinear dynamic system, and the results calculated by ANN simulating model were in good agreement with the tested ones.

I. Introduction

ZnO varistor belongs to sintered polycrystal ceramics, which is a kind of semiconductor containing a small amount of other metal oxides (such as Bi_2O_3, CoO, MnO, Sb_2O_3 and Cr_2O_3 et al.), exhibiting highly nonlinearity similar to back-to-back Zener diodes but with much greater current and energy absorption capabilities, which are widely used as surge arresters in power system based on their excellent nonlinearity. The ZnO surge arresters ensure the safe operation of power system by against the lightning and switching overvoltage. So they must have the characteristics of stable operation, their stabilities of ZnO surge arresters are the balance between the power loss and thermal dispersing ability of varistor[1-7]. The properties of power losses of ZnO varistors would decide the operating reliability and their life-spans. So to research the properties and build the simulating model of power losses of ZnO varistors is useful to analyze the thermal characteristics and stability of ZnO surge arresters.

II. Measurement System of Power Losses

The measurement system of power loss is illustrated in Figure 1. The tested ZnO varistor was put into the oven. The temperature of the oven was measured and controlled by temperature measuring and controlling systems. The applied voltage ratio q is defined as the ratio of the maximum value U_{max} of applied voltage divided by 1 mA DC voltage U_{1mA} of the tested ZnO varistor. During the experiment, the temperature was changed in the ranges from 20℃ to 205℃, and applied voltage ratio q was altered from 0.2 to 1.05. The tested varistors were commercial ones which were used in 110 kV and 220 kV surge arresters. The varistor had a ring shape, its diameter was 71 mm, the diameter of the inner hole was 26 mm, and the height was 20.5 mm. The power losses of ZnO varistors under different temperature and different voltage ratio were measured by power loss measuring system. When the temperature T was fixed in a value, then the power loss P under different q was measured. A large number of tested results were obtained.

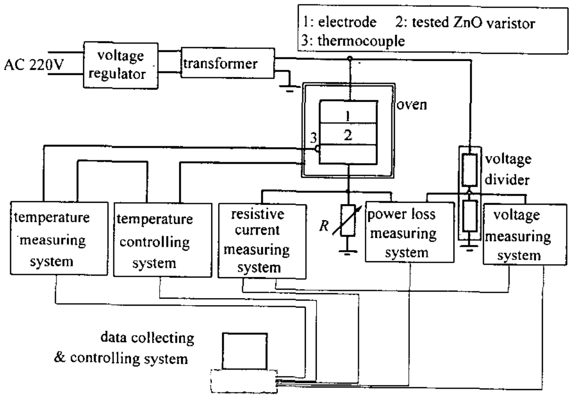

Fig. 1. The measurement system of power loss.

III. Characteristics of Power Losses

The power loss P increases with the increase of the applied

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Jin-Liang He is with Department of Electrical Engineering, Tsinghua University, Beijing 100084, China.
H. G. Cho and S. W. Han are with Division of Electrical Materials, Korea Electrotechnology Research Institute, Changwon, Korea.

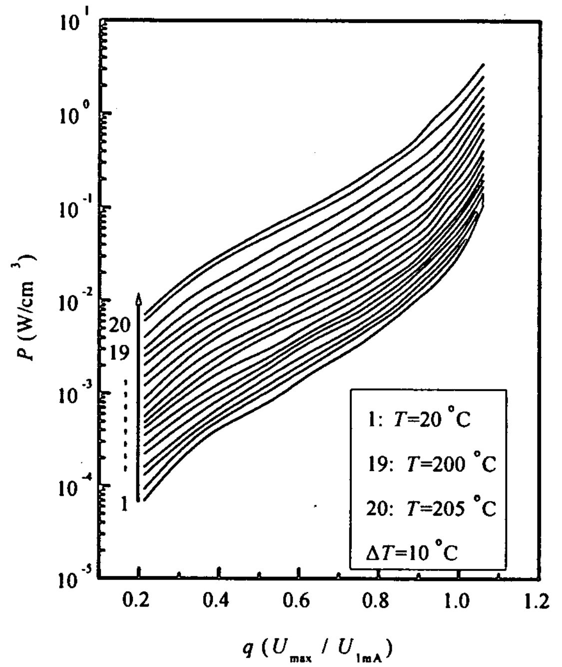


Fig. 2. The relation between power losses P and the applied voltage ratio q from test results.

voltage ratio q from test results (Figure 2), we can observe that q with the value of about 0.85 is a turn point of the P-q curve, when q is less than about 0.85, the increase of the power loss is slow. But when q is larger than 0.85, the power losses increase quickly, and the values of power losses are large too. The turn point is decided by the prescription and manufacturing technology of ZnO varistors, we think different ZnO varistors manufactured by different prescriptions and manufacturing technologies of different manufacturers would have different turn points. When the applied voltage ratio q is higher than about 0.85, the generated heat is very high because the power loss increases quickly. So the surge arresters manufactured by this type of ZnO varistors tested in the experiment should not be permitted to operate above the applied voltage ratio 0.85.

The relation between the temperature and the power loss is shown in Figure 3 from test results. The power loss increases with the increase of temperature, the relation can be described by exponent function $P = a\exp(bT)$, a and b are constants related to applied voltage ratio q.

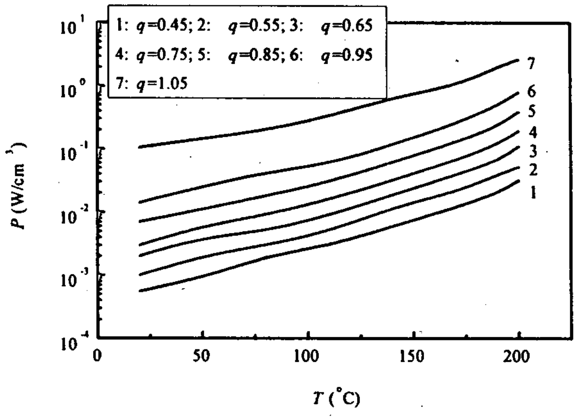


Fig. 3. The relation between power losses P and temperatures T from test results.

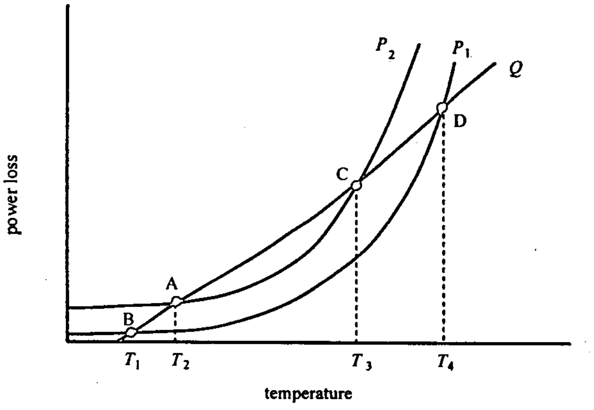


Fig. 4. The heat balance diagram.

The heat balance diagram is often used to analyze the thermal stable property of ZnO surge arresters (Fig. 4). Q is the thermal power loss of varistors to environment at fixed ambient temperature (60℃), P_1 and P_2 are the power losses at different applied voltage ratio q_1 and q_2, respectively, and $q_2 > q_1$. Curve P and curve Q have two crosspoints, crosspoints A and B are the stable operating points, T_1 and T_2 are the operating temperatures. Crosspoints C and D are the limited operating points, T_3 and T_4 are the limited operating temperatures. When the temperature of ZnO varistors inside an arrester exceeds the limited operating temperature, then the arrester would be broken down. The difference between the operating temperature and limited one is used to measure the thermal stable capability. The temperature difference at q_2 is less than that at q_1, that is to say, the ZnO surge arrester operating in small q has a better thermal stable capability than that in large q. The temperature difference is the permitted temperature rise. When the ZnO varistors as surge arresters operate in the power system, they must absorb the energies of lightning and switching overvoltages. But the time delays of overvoltages are very short, so the courses could be treated as thermal insulation ones. When the varistors absorb a lot of overvoltage energies E, then their temperatures would increase to a high value, if the arrester operates in q_2, then the temperature would exceed the limited temperature T_3, and the arrester would be thermally destroyed. But if the arrester operates in q_1, then the temperature after absorbing overvoltage energy would not exceed the limited temperature T_4, and the temperature of varistor would return to the operating temperature T_1. So, the varistors inside arrester could not be permitted to operate in high q. The applied voltage ratio of the tested varistors would not be permitted to exceed about 0.85 when they work in power system.

IV. ANN Simulating Model of Power Losses

In order to analyze the thermal balance of ZnO surge arresters, first the power loss model should be obtained. The power loss of ZnO varistors is a complicated function of applied voltage ratio and temperature illustrated in Figure 2. It is difficult to be described precisely by popular methods. A general exponent function was used to simulate the power loss in [7], the precision was not high. And a linear interpolation method was adopted in [1], this method was difficult to eliminate the noise of experimental results.

The Artificial Neural Network(ANN) consists of a lot of neurons. It is an adaptive nonlinear dynamic system, which stores the information in the weight among neurons and has a good wrong-permitting capability, and can eliminate the noise in the experimental result[8]. The ANN consists of input layer, hidden layers and output layer(Figure 5). The ANN model changes the weights by a learning course, and reaches the demanded precision.

The inputs of neurons in *j*th layer are

$$net_j = \sum W_{ji} O_i \tag{1}$$

where W_{ji} is the weight between *j*th and *i*th layers. And the output O_j of the neuron is

$$O_j = f(net_j) \tag{2}$$

where f is an exciting function of neuron:

$$O_j = \frac{1}{1+e^{-(net_j+a_j)}} \tag{3}$$

where a_j is the valve value of neuron. The square error E between ANN output $\{O_k\}$of M samples and expecting output $\{t_k\}$ is:

$$E = \frac{1}{2}\sum_k (t_k - O_k)^2 \tag{4}$$

The increasing value $\triangle W_{kj}$ of weight in the learning course in output layer is:

$$\triangle W_{kj} = \eta O_j (t_k - O_k) O_k (1 - O_k) \tag{5}$$

here is the learning velocity. The increasing value of weight in the learning course in hidden layers is:

$$\triangle W_{ji} = \eta O_i O_j (1 - O_j) \sum_k \delta_k w_{kj} \tag{6}$$

Here

$$\delta_k = (t_k - O_k)(1 - O_k) O_k \tag{7}$$

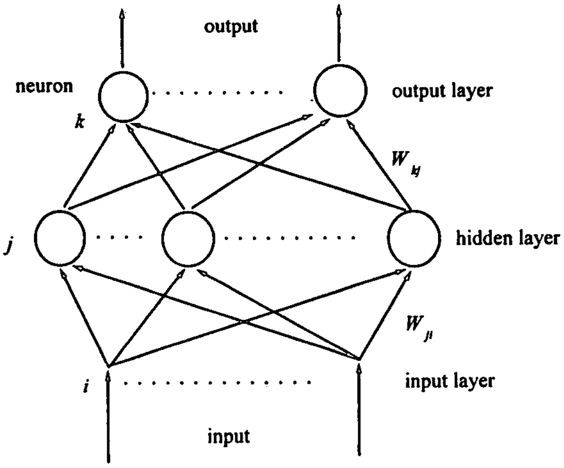


Fig. 5. ANN model.

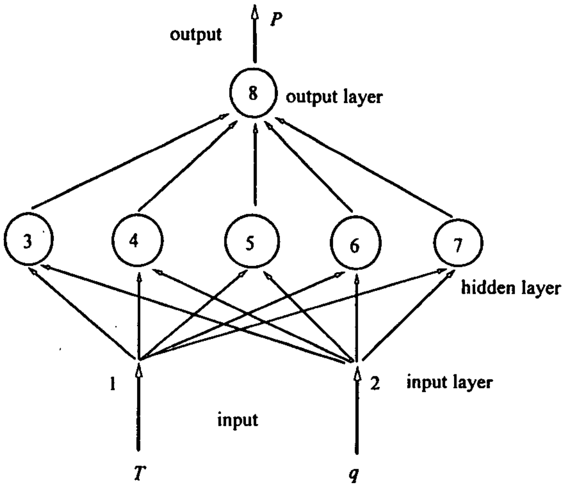


Fig. 6. The ANN simulating model of power losses of ZnO varistors.

According to the course introduced above, the weights and valve values satisfying the precise demand would be obtained by repeatedly learning course by using the provided samples (here samples are experimental results).

The ANN model used to simulate the power loss of ZnO varistors is shown in Figure 6, which have a hidden layer and 6 neurons. The applied voltage and temperature are the input layers, and the power loss is the output layer. The experimental results were imported into ANN to study, the suitable weights and valve values were obtained in Table 1 after learning course. So the power loss could be described by next equation:

$$P = 4.0f[\sum_{j=3}^{7} W_{8j}(0.754qW_{1j} + 0.004TW_{2j} + a_j) + a_8] \tag{8}$$

where T is the temperature, its unit is K.

The comparison between the experimental and the calculating results of ANN simulating model is illustrated in Figure 7, there

Table 1. The weights and valve values of the ANN simulating model of ZnO varistor.

q	$q \leq 0.80$	$q > 0.80$
W_{13}	2.2458	4.3928
W_{14}	-18.6792	-18.7469
W_{15}	2.8669	1.9528
W_{16}	-8.2380	-8.8511
W_{17}	6.3022	2.7642
W_{23}	6.4557	7.6803
W_{24}	0.8536	0.1910
W_{25}	1.4727	-1.3617
W_{26}	-29.4428	-29.4257
W_{27}	2.7679	-1.0962
W_{83}	6.2096	4.4670
W_{84}	-9.1872	-8.7604
W_{85}	2.8100	2.2910
W_{86}	-14.6826	-14.2848
W_{87}	5.3462	3.2419
a_3	7.1236	-7.5899
a_4	15.6502	16.3475
a_5	-0.8328	0.7929
a_6	33.5978	33.2990
a_7	-2.3770	-0.0870
a_8	2.1493	2.5599

is a good agreement between them.

V. Conclusions

The property of power loss of ZnO varistors is related to the thermal stability of ZnO surge arresters. The power losses of ZnO varistors under different temperatures and applied voltages were measured.

The power losses increase with the increase of the applied voltage ratio, when the applied voltage q is less than about 0.85, the increase of the power loss is slow. But when q is larger than about 0.85, the power losses increase quickly, and the values of power losses were large too. So the surge arresters manufactured by this type of ZnO varistors tested in the experiment should not be permitted to work above the applied voltage ratio 0.85. The power losses increase with the increase of temperature.

The Artificial Neural Network (ANN) is an adaptive nonlinear dynamic system. The ANN was used to simulate the power losses properties of ZnO varistors, and the calculated results by ANN simulating model were in good agreement with the tested ones. The ANN simulating model could be conveniently used to analyze the thermal stability of ZnO varistor.

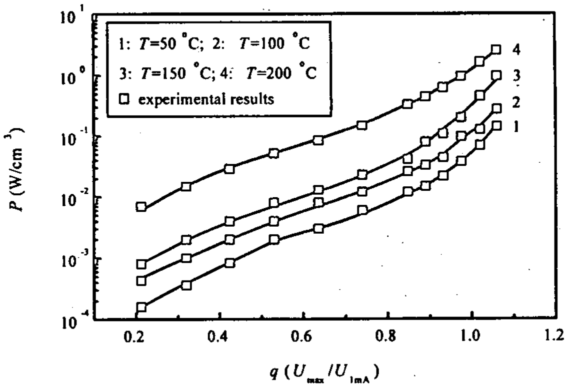


Fig. 7. The comparison between the experimental and the calculating results of ANN simulating model.

References

[1] M. V. Lat, Analytical method for performance prediction of metal oxide surge arresters, *IEEE Trans. on Power Apparatus and System*, Vol. PAS-104, No. 10, pp. 2665-2674, Oct. 1985.

[2] Guy St-Jean and Andre Petit, Metal-oxide surge arresters operating limits defined by temperature-margin concept, *IEEE Trans. on Power Delivery*, Vol. PWRD-5, No. 2, pp. 627-633, April 1990.

[3] W. G. Carlson, T. K. Gupta and A. Sweetana, A procedure for estimating the lifetime of gapless metal oxide surge arresters, *IEEE Trans. on Power Delivery*, Vol. PWRD-1, No. 1, pp. 67-74, Jan. 1986.

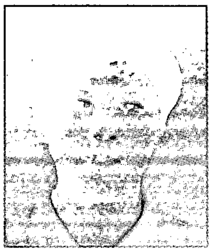
[4] M. Kan, S. Nishiwaki, T. Sato, S. Kojima and S. Yanabu, Discharge capability and thermal stability of a metal oxide surge arrester, *IEEE Trans. on Power Apparatus and System*, Vol. PAS-102, No. 2, pp. 282-289, Feb. 1983.

[5] M. Mizuna, M. Hayashi and T. Mitani, Thermal stability and life of the gapless surge arrester, *IEEE Trans. on Power Apparatus and System*, Vol. PAS-100, No. 5, pp. 2664-2674, May 1981.

[6] Y. Fujiwara, Y. Shibuga, M. Imataki and T. Nitta. Evaluation of surge degradation of metal oxide surge arresters, *IEEE Trans. on Power Apparatus and System*, Vol. PAS-102, No. 5, pp. 1384-1390, May 1983.

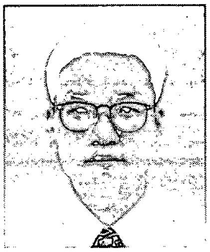
[7] S. Nishiwaki, H. Kimura, T. Satoh, H. Mizoguchi and S. Yanabu, Study of runaway/equivalent prorated model of a ZnO surge arrester, *IEEE Trans. on Power Apparatus and System*, Vol. PAS-103, No. 2, pp. 413-421, Feb. 1984.

[8] Yoh-Han Pao, *Adaptive pattern recognition and neural networks*, Addison-Wesley Publishing Company Inc., New York, p. 1, 1980.



Jin-Liang He was born in Changsha, China, in 1966. He received Ph. D. degree in electrical engineering from Tsinghua University, China, in March 1994. He became an associate professor in Electrical Engineering Department, Tsinghua University. During 1994 to Jan. 1997, he was the head of high voltage laboratory in Tsinghua University. Since April 1997, he has been a visiting scientist in Korea Electrotechnology Research Institute. His research interests are in overvoltage and EMC in power system and electronic system, grounding technology, electrical materials and power apparatus.

Han-Goo Cho was born in Chungnam, Korea, in 1959. He received the B.S., M.S. and Ph.D. degrees in electrical engineering from Sung Kyun Kwan University in 1984, 1987, 1996, respectivity. He also received the P.E. certificate of electric machine in 1992. Since 1987, he is researcher in KERI (Korea Electrotechnology Research Institute), and now the head of insulator and arrester technology research team at KERI. His research interests include non-ceramic arrester, insulators, power apparatus and properties of electrical materials.



Se-Won Han was born in Seoul in 1961, and received his B.S. and M.S. degrees in electrical engineering from Hanyang University, Korea in 1984 and 1986, respectively. Since 1986, he is researcher in KERI (Korea Electrotechnology Research Institute) and now senior researcher of KERI and doctoral student in electrical engineering at Hanyang University. His research interests are in non-ceramic arresters, insulators and ZnO varistor characteristics.