Regression Analysis of Vibration Phenomenon on the Load Capacity and Elapsed Year of a Power Transformer

Young-Dal Kim*

Abstract

The majority of the causes for the failures of power transformers in operation are mechanical defects due to vibration. The vibration phenomenon was measured from the power transformers in operation in the substations. The vibration measurement was performed in a 6×4 structure on one side of each transformer. The vibrations of the measured points were presented in two and three dimensions and analyzed. The results, according to the elapsed year of the transformer and the load capacity to the transformer, were analyzed. These results could be used as basic data with which to establish vibration standards for power transformers. In addition, the load capacity-vibration phenomenon correlation was examined and regression analysis was performed to derive the estimation function. The vibration phenomenon according to the elapsed years was also estimated to derive the function. Then the analysis of the power transformers was used to set vibration standards for them based on the vibration data.

Key Words : Transformer, Vibration, Correlation, Regression Analysis, Elapsed Year

1. Introduction

The power transformer is an important power equipment for the supply of the power generated from generation plants to customers.. As such, it requires high reliability. The causes of transformer failures and the resultant operating stoppages have been analyzed, and it was reported that they were caused by mechanical problems in the transformers in addition to electrical problems[1-2].

As a result of the measurement/analysis of the vibration of power transformers that failed, partial resonance phenomena were found that had enlarged the vibration amplitude of the transformer. Because of the lack of technical measures of the problems caused by vibration in the transformer design and manufacturing process, the failures from mechanical damage in the elapsed years of the transformer have not been decreasing.

The soundness of transformers is currently judged only with respect to the electrical insulation characteristics of its wiring and the chemical test of its insulation oil. As such, there

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are few fundamental measures against the mechanical damages and failures of transformers[3-4].

It is very difficult to find the cause of a mechanical failure since there are no mechanically operating sections in the transformer. In Korea, there has been no research on the mechanical soundness of transformers. The mechanical soundness can be judged through such processes as structural analysis and vibration resistance treatment during the manufacturing process, but the vibration is not tested in the design, manufacturing, and operating processes since there are no detailed technical standards and procedures on vibration, which is important in terms of maintenance.

Outside Korea, studies to detect loose iron cores or wirings in transformers are underway using the vibration signals generated from the transformer. No mechanical soundness judgment technique has yet been established, however, even outside Korea[5-6].

Therefore, for the power transformers (154[kV]) in operation in the substations within the jurisdiction of the Daejeon Power Transmission District Office of the Korea Electric Power Company (KEPCO), vibration phenomena in 24 sections (6×4) on one side of each transformer were measured according to their diverse load capacities and elapsed years. An estimation function was derived by identifying the correlation between the load capacity and vibration using the regression analysis, and by analyzing the correlation between the elapsed years and vibration[7].

The results of the analysis, which are presented in this paper, can be used to establish vibration standards for power transformers.

2. Regression Analysis

Regression analysis can be defined as a statistical analysis method to identify the correlations between variables, since it presents a very simple and clear way of finding functional correlations between multiple variables5.

Regression analysis calculates the estimated values using samples, and estimates the variables that represent the correlations between populations using the estimated values, to identify the correlations between populations of independent variables and dependent variables. The regression model can be used for many purposes.

It can be used to evaluate the importance of each independent variable, analyze the effect of changing the standards, including changing the level of the independent variables, and estimate the values of the independent variables when the functional correlations between the variables and the sets of independent variables are given.

3. Vibration Test

In this study, the vibration levels of power transformers in operation were measured in compliance with KS B 0714 (Mechanical vibration and impact: Mechanical installation of the accelerometer, 2001)[8].

The subjects in this study were 32 power transformers in nine substations within the jurisdiction of the Daejeon Power Transmission District Office of KEPCO. They were 154[kV] power transformers (60[MVA]×31; 40[MVA]×1) with a voltage ratio of 154/23[kV] (YY connection). Their elapsed years were less than 10 years (15 transformers); 10 years or more but less than 20 years (12 transformers); and 20 years or more but less than 30 years (5 transformers).

The types and manufacturers of the transformers varied according to each substation's installation sequence. Phase A was set as the reference for the separable transformers (but not for the single-body three-phase transformers). Only the accessible areas were measured, and the operating conditions, installation conditions, and load capacity at the time of the measurement were also used to analyze the data. Fig. 1 shows a diagram of the vibration measurement of the transformers in operation.

The data acquisition/analysis equipments used were a RION PV-95 accelerometer, a UV-06A charge amplifier, and RION and B&K 3039 pulse equipment and computers. The frequency range for the measurement was set at 0~3.2[kHz] (frequency step = 1[Hz]).

The vibration measurement on one side (divided into 6×4 sections) of the transformers in operation by attaching an accelerometer to each. The positions of the accelerometer attached to the transformers.

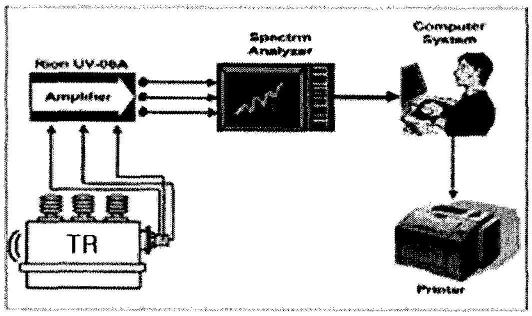

Fig. 1. Block diagram of the vibration measurement and analysis system

4. Test Results and Analysis

4.1 Test Results

The specifications of the transformers whose vibrations were measured. The substations were symbolized as A, B, C, D, E, F, G, H, and I. The sets of transformers were designated as nos. 1 and 2 and nos. 1, 2, 3, and 4. For example, A2 refers to transformer no. 2 in substation A.

Most of the transformers were single-phase transformers, but some were three-phase transformers. The three manufacturers were represented as A, B, and C, and the years of manufacture were uniformly distributed from 1983 to 2007. The load capacity was the value of the load applied to the transformer at the time of the vibration measurement

In this study, vibration was measured in the 32 subject transformers. Table 1 shows the vibration measurement results according to the load capacity of the single-phase transformers, and Table 2 shows the measurement results according to the load capacity of the three-phase transformers.

Table 1. Results of the vibration measurement of single-phase transformers according to their diverse load capacities (mm/s)

Subst.	Manu.	Year	Load Capacity	Vibration Level
F1	A	2001	16.3	1.1E-06
F3	B	1996	17.8	1.3E-06
F4	C	2003	21.9	1.4E-06
D3	A	2005	23.0	9.4E-07
F2	A	2001	23.3	1.4E-06
B4	B	1998	25.0	1.5E-06
D1	A	2002	25.3	1.3E-06
B1	A	1992	31.0	1.4E-06
G3	C	1995	33.3	1.1E-06
G4	C	2004	33.8	1.0E-06
H2	A	2001	34.0	1.1E-06
B3	B	1996	35.0	1.7E-06
B2	A	1992	36.0	1.8E-06
H1	A	2001	37.0	1.2E-06
H3	A	2004	37.0	1.3E-06
H4	C	2003	38.0	1.3E-06
I4	B	2007	38.0	1.7E-06
I2	A	1996	39.0	1.5E-06
I3	B	2007	39.0	1.3E-06

Table 2. Results of the vibration measurement of three-phase transformers according to their diverse load capacities (mm/s)

Subst.	Manu.	Year	Load Capacity	Vibration Level
D4	C	1984	6.4	1.7E-06
A1	A	2006	10.0	1.3E-06
A2	A	2006	10.0	1.3E-06
D2	B	1990	15.0	1.1E-06
G1	B	1990	24.6	1.5E-06
C1	C	1984	28.0	1.8E-06
C2	C	1987	29.0	1.1E-06
E2	C	1983	31.8	1.9E-06
I1	C	1988	32.0	1.3E-06
E3	C	1990	33.6	1.5E-06
G2	B	1993	33.8	1.3E-06
E4	A	1991	34.5	1.9E-06
E1	C	1983	34.6	2.9E-06

4.2 Analysis of the Results

The vibrations according to the load capacities of the transformers are shown in Fig. 2. Fig. 2 shows the values of the vibrations according to diverse load capacities of the single-phase transformers. The estimation function was derived from the analysis of the vibration trend according to the changes in the load capacity using the regression analysis of the vibration values.

The linear fit and the polynomial fit were applied to the regression analysis. Eq. 1 is the estimation function by the linear fit, with a COD value of 0.26, which indicates a normal correlation.

$$y = (8.3e^{-9})x + 1.1e^{-6} \tag{1}$$

Eq. 2 is the estimation function by the polynomial fit, with a COD value of 0.07, which indicates an unreliable correlation.

$$y = (1.1e^{-10})x^2 + (1.9e^{-9})x + 1.2e^{-6} \tag{2}$$

The results of the linear fit and the polynomial fit indicated that the vibration trend according to the load capacity was more reliable in the case of the linear fit, for the single-phase transformers.

Fig. 3 shows the vibration values according to the load capacities of the three-phase transformers. The estimation function was derived from the analysis of the vibration trend according to the changes in the load capacity using the regression analysis of the vibration values.

The linear fit and the polynomial fit were applied to the regression analysis, as with the single phase transformers.

Eq. 3 is the estimation function by the linear fit, with a COD value of 0.39, which indicates a satisfactory correlation.

$$y = (1.7e^{-8})x + 1.2e^{-6} \tag{3}$$

Eq. 4 is the estimation function by the polynomial fit, with a COD value of 0.31, which indicates a reliable correlation, as with the linear fit.

$$y = (3.1e^{-9})x^2 - (1.1e^{-7})x + 2.2e^{-6} \tag{4}$$

The results of the linear fit and the polynomial fit indicated that the vibration trend according to the load capacity was reliable in both the linear fit case and the polynomial fit case, for the three-phase transformers. When the results were analyzed more precisely, the linear fit seemed more reliable than the polynomial fit.

Accordingly, for single-phase or three-phase transformers, the linear fit could be more reliable in the regression analysis of the vibration trend according to diverse load capacities.

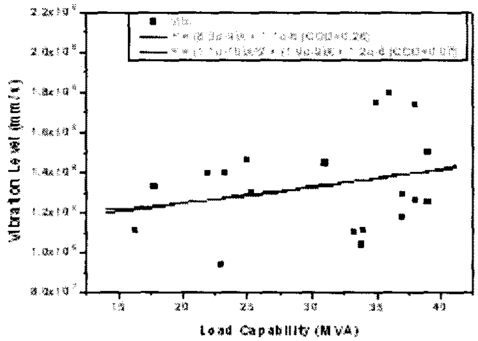

Fig. 2. Results of the regression analysis of the vibration of single-phase transformers according to various load capacities

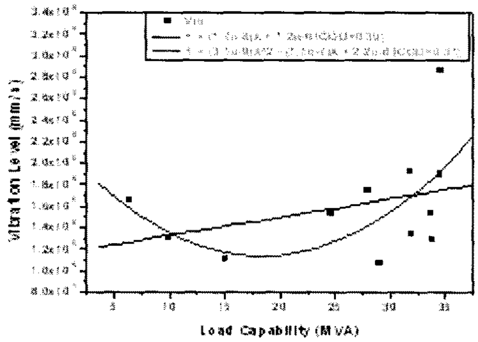

Fig. 3. Results of the regression analysis of the vibration of three-phase transformers according to various load capacities

Table 3. Vibration according to Various Frequencies in Each Substation

[Unit: (e4) mm/s]

Substation	120[Hz]	240[Hz]	360[Hz]	480[Hz]
A	1.87	0.38	0.39	0.44
B	1.95	0.29	0.70	1.53
C	0.86	1.65	1.07	0.44
D	0.81	1.15	0.43	0.45
E	6.12	5.00	2.19	0.97
F	3.08	0.67	0.33	0.16
G	1.64	1.04	0.79	0.44
H	2.23	1.86	0.25	0.29
I	0.62	0.28	0.46	0.32

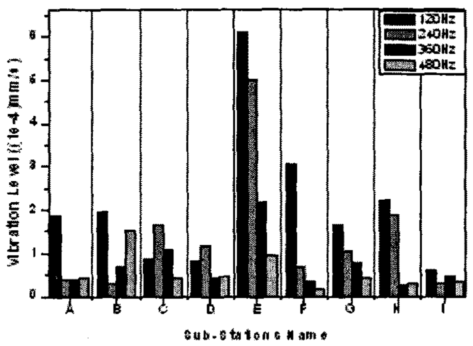

Fig. 4. Vibration according to various frequencies in each substation

Table 3 shows the average vibration measured at each substation according to various frequencies. Fig. 4 shows the vibration at each substation according to various frequencies.

As shown in the said figure and table, substation E showed the highest vibration values for all the frequencies (120, 240, 360, and 480[Hz]). Substation I showed the lowest vibration values for all the said frequencies. These seem to have been because of the aging of the transformers during their elapsed years.

For a closer inspection of Fig. 4, and Fig. 5 shows the vibration according to the frequencies in substation E, which had the highest vibration values.

As shown in the figure, there was a strong vibration at the left side of the transformer in the case of 120[Hz], and only a weak vibration at the right side. There was a vibration at the right upper side in the case of 240[Hz], but none at the other sections. In the case of 360[Hz], there was a strong vibration at the middle section of the transformer, and hardly any vibration at the other sections. In the case of 480[Hz], there was a vibration at the upper right side, as in the case of 240[Hz].

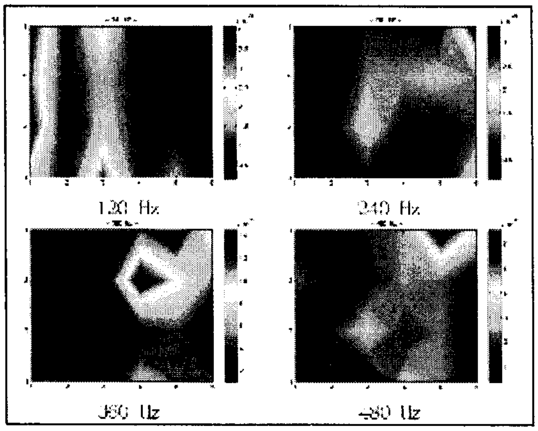

Fig. 5. Vibration according to the various frequencies in substation E

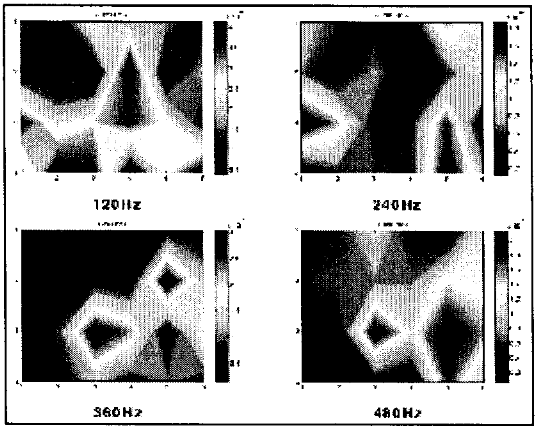

Fig. 6. Vibration according to the various frequencies in substation I

For an even closer inspection of Fig. 4, Fig. 6 shows the vibration according to the frequencies in substation I, which had the lowest vibration values.

As shown in the figure, there was a strong vibration over a wide area around the middle section of the transformer in the case of 120[Hz]. In the case of 240[Hz], there was a vibration at the outer sections, and hardly any at the other sections. In the case of 360[Hz], there was a vibration that was weaker than in the case of 120[Hz] at the middle section, but hardly any at the other section. Also in the case of 480[Hz], there was a vibration at the middle section and the right section, as in the case of 360[Hz].

The vibration level according to the elapsed years was also analyzed. Fig. 7 shows the case of a single-phase transformer, which indicates that the vibration level increased as the number of elapsed years increased. This phenomenon was analyzed in detail using regression analysis. Only the linear fit was used, however, since the polynomial fit does not ensure the reliability of the correlation values and is not suitable for analyzing vibration phenomena according to the elapsed years. Eq. 5 shows the estimation function, with a COD value of 0.39, which is very satisfactory.

$$y = -(2.0e^{-8})x + 4.1e^{-5} \tag{5}$$

Fig. 8 shows the vibration values according to the elapsed years and the regression analysis results for the case of a three-phase transformer. Only the linear fit was used here, with a COD value of -0.47, which was very satisfactory. Eq. 6 is the estimation function that resulted from the regression analysis.

$$y = -(2.9e^{-8})x + 5.9e^{-5} \tag{6}$$

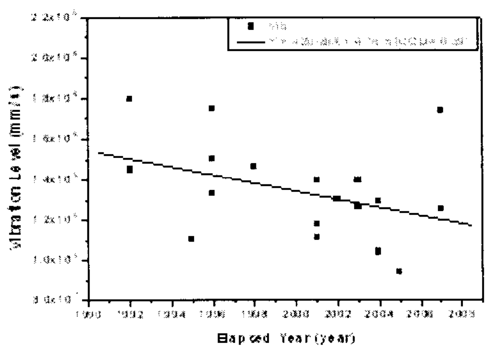

Fig. 7. Results of the regression analysis of vibration according to the elapsed years for the single-phase transformer

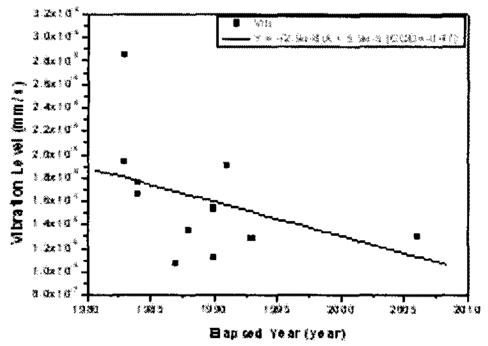

Fig. 8. Results of the regression analysis of vibration according to the elapsed years for the three-phase transformer

5. Conclusion

In this study, the vibration levels of 32 power transformers (154[kV]) in operation in nine substations within the areas of Daejeon and Chungnam were measured.

The variations in the vibration level according to the load capacity were analyzed using regression analysis. After analyzing the COD values and deriving the estimation function, the following conclusions were reached.

Phase	Fit Type	Estimation function	COD	decision
1	Linear	$y = (8.3e^{-9})x + 1.1e^{-6}$	0.26	normal
	Poly-nomial	$y = (1.1e^{-10})x^2 + (1.9e^{-9})x + 1.2e^{-6}$	0.07	slight
3	Linear	$y = (1.7e^{-8})x + 1.2e^{-6}$	0.39	good
	Poly-nomial	$y = (3.1e^{-9})x^2 - (1.1e^{-7})x + 2.2e^{-6}$	0.31	good

The comparison of the vibration levels according to the load capacity by the linear fit and the polynomial fit showed that the analysis by the polynomial fit was not reliable, whereas the analysis by the linear fit was reliable. For the three-phase transformer, both the linear fit and the polynomial fit were reliable, but the linear fit was more reliable.

Accordingly, for single-phase or three-phase transformers, the linear fit seems to be more reliable in a regression analysis of the vibration trend according to the load capacity.

The variations in the vibration level according to the transformers' elapsed years were also analyzed using regression analysis. After analyzing their correlation and deriving the estimation function, the following conclusions were reached.

Phase	Fit Type	Estimation function	COD	decision
3	Linear	$y = -(2.0e^{-8})x + 4.1e^{-5}$	0.39	good
	Linear	$y = -(2.9e^{-8})x + 5.9e^{-5}$	-0.47	good

Accordingly, it seems that the vibration level for a condition of an unknown state can be estimated using the estimation function of the vibration level according to the load capacity and the elapsed years.

These estimated results could be used as reliable data in diagnosing the soundness of power transformers in operation, and in establishing vibration standards for power transformers.

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Biography

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