Determination of Transformer Rating Based on Total Harmonic Distortion Under Balanced Conditions

S. Masri* and P.-W. Chan

School of Electrical and Electronic Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Pulau Pinang, Malaysia

*Corresponding author: syaf@eng.usm.my

Abstract: *In the present article, the effects of a non-linear load under balanced conditions on the rating of a transformer are analysed. Non-linear loads are related to temperature increases in a transformer, which lead to deterioration and reduction of lifetime. Due to the unwanted effects of harmonic components in non-linear loads, the load connected to the transformer should be reduced. In other words, to supply a specific load, the rating of the transformer should be increased to sustain the rise in heat. The aforementioned methods of overcoming the effects of non-linear loads are known as de-rating. By assuming that the transformer's rating is a linear function of the THD, a method of selecting the transformer's rating based on the total harmonic distortion (THD) of the load was developed in the present study.*

Keywords: de-rating, harmonic components, linear and proportional, transformer rating

1. INTRODUCTION

Transformers play an important role in power systems and are used to increase or decrease the line voltage in transmission and distribution systems. In power systems, there is no room for error or transformer malfunctioning. Therefore, the quality and reliability of the transformer are important parameters. In recent years, the use of non-linear loads has increased rapidly. Large, non-linear loads have a significant impact on the temperature of a transformer[1] as the current flowing through the system increases the heat. Under linear conditions, the current is only produced by the fundamental component, but under non-linear conditions, the current contains fundamental and harmonic components of higher order. As the harmonic components of the current become more significant, the THD increases. As a result, the amount of current flowing through the transformer under a constant load increases, which subsequently increases the temperature of the transformer.

An abnormal increase in the temperature of the transformer deteriorates the insulation and potentially reduces its lifetime.[2] Additionally, abnormal temperature increases also reduce the power factor, productivity, efficiency, capacity and performance of the plant.[3,4]

Two methods can be utilised to address this problem; first is by reducing the maximum load on the transformer, and second is to use a transformer with higher rating to allow the same load. Both of the aforementioned methods are known as de-rating.[5,6] A higher rated transformer can supply a higher load current, and the selection of a transformer for a specific load is an important process. For instance, if the demand is less than the load, the system will not be cost effective. Alternatively, if the load is too high, the system will be overloaded. Therefore, in the present study, a method for selecting a transformer's rating based on the amount of THD was developed by assuming that the THD is linearly related to the temperature and rating of the transformer.

2. EXPERIMENTAL

Under non-linear load conditions, the load current contains fundamental and harmonic components of higher order and can be expressed as:

$$I_L = I_{LI} \sin \omega_1 t + \sum_{h=3,5,7...} I_{Lh} \sin \omega_h t \qquad (1)$$

where

I_L = *load current*

I_{LI} = *fundamental load current*

I_{Lh} = *odd order h of current harmonic component*

$\omega_1 = 2\pi f_1$

f_1 = *fundamental frequency*

$\omega_h = h \times f_1$

$h = 3, 5, 7, 9...$

Under linear load conditions, the load current only contains the fundamental component. In the present study, we assumed that the THD was proportional to the total harmonic components of the non-linear load. Thus, as the 3rd, 5th, 7th and 9th harmonic component increased, an increase the THD was observed. Because the fundamental component was kept constant, under linear conditions, the THD increased with an increase in the number of harmonic components. As the THD increased, the temperature of the transformer increased due to the current flowing through the system.[7] Therefore, because the rating is closely related to the temperature, the transformer rating should be increased as the THD increases.[8]

3. RESULTS AND DISCUSSION

Figure 1 shows a schematic representation of the experimental equipment, and Figure 2 shows the temperature monitoring sites of the three-phase transformer.

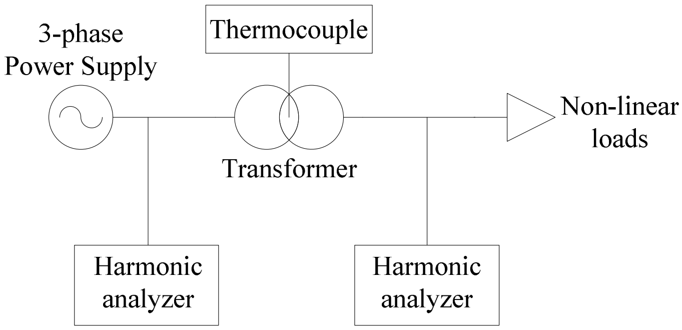

Figure 1: Schematic depiction of the experimental equipment.

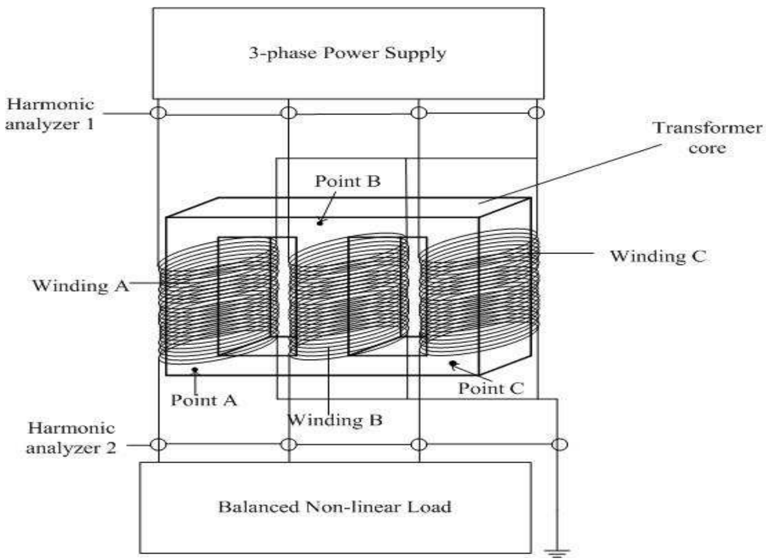

Figure 2: Schematic diagram of the heat measurement sites on the transformer.

A pure sinusoidal three-phase power supply was supplied to a non-linear load connected to a three-phase transformer. The THD was adjusted according to the total load, which consisted of a linear and non-linear load. The total load was kept constant at the transformer rated current. The harmonic spectrum was recorded by a harmonic analyser on the primary and secondary side of the transformer, and three thermocouples were attached to the winding of the transformer to measure the temperature at different THD values. Figures 3 to 11 show the data obtained from the harmonic analyser.

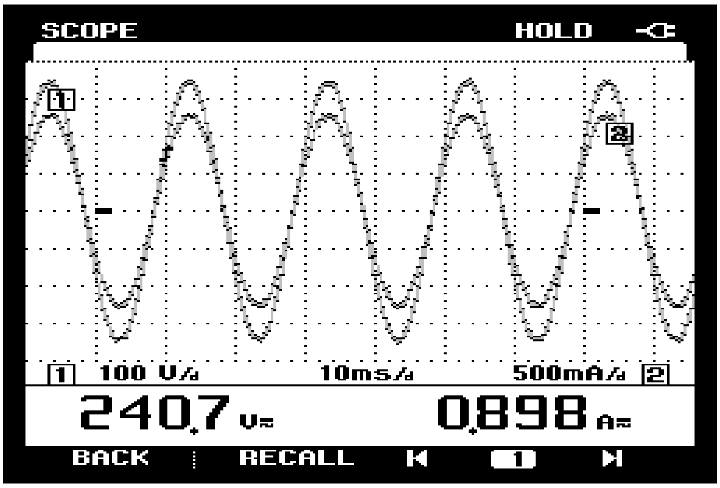

Figure 3: Line voltage and current waveform at a THD of 0%.

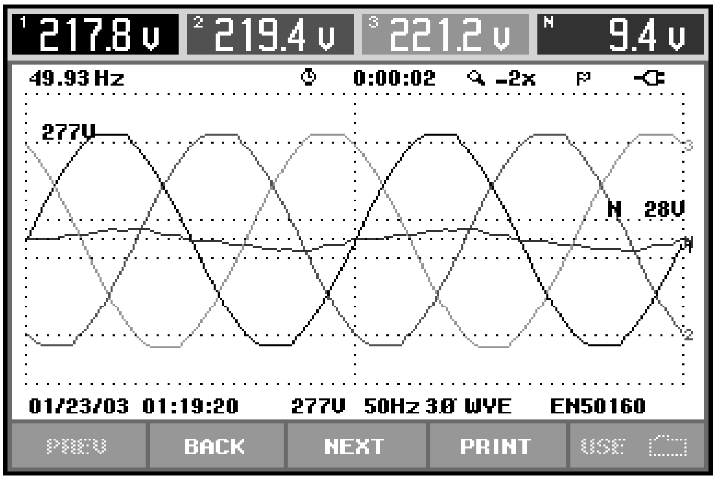

Figure 4: Line voltage waveform at a THD of 7.8%.

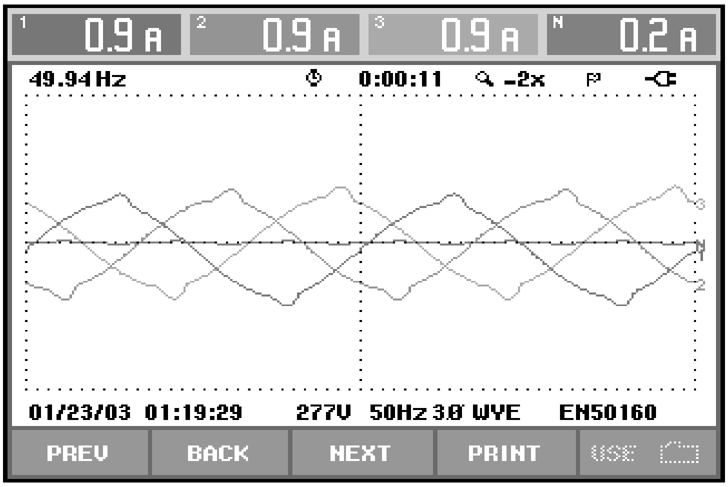

Figure 5: Line current waveform at a THD of 7.8%.

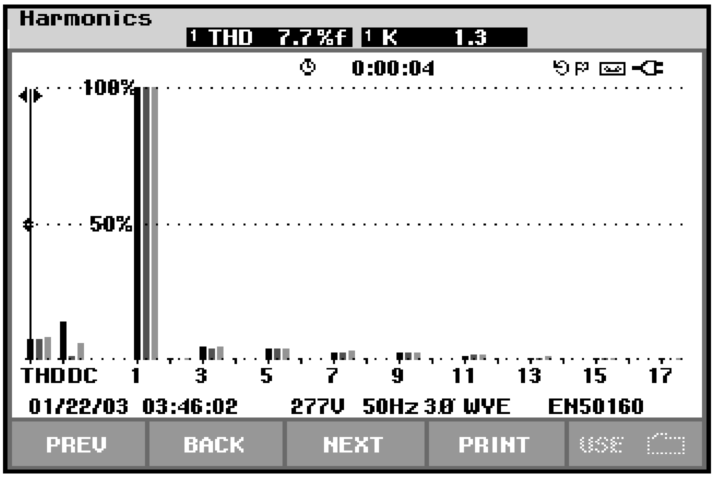

Figure 6: Harmonic component distribution at a THD of 7.8%.

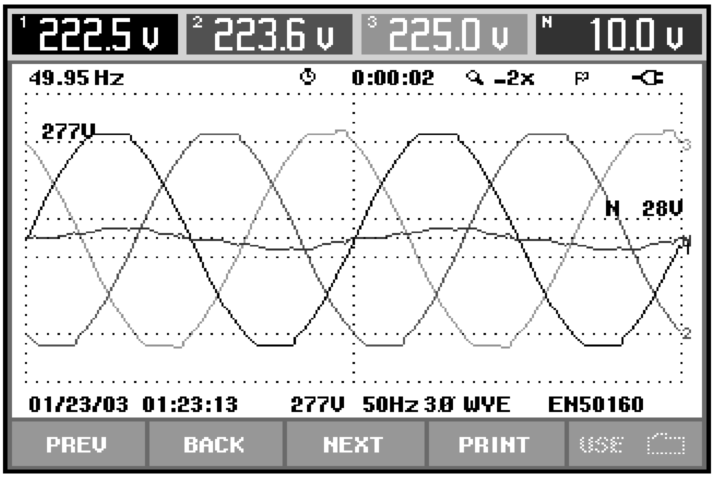

Figure 7: Line voltage waveform at a THD of 14.57%.

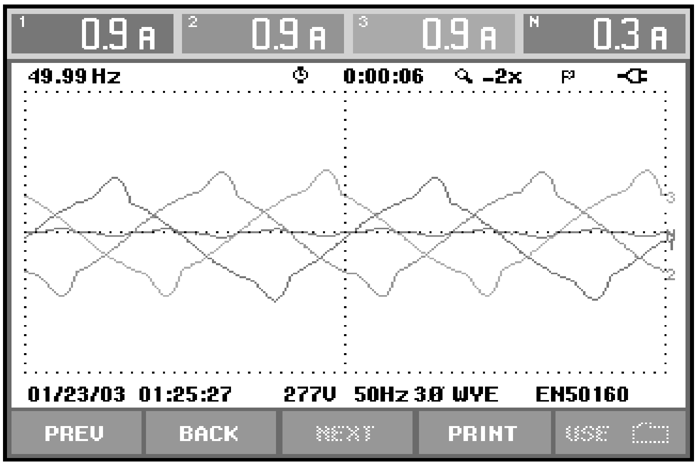

Figure 8: Line current waveform at a THD of 14.57%.

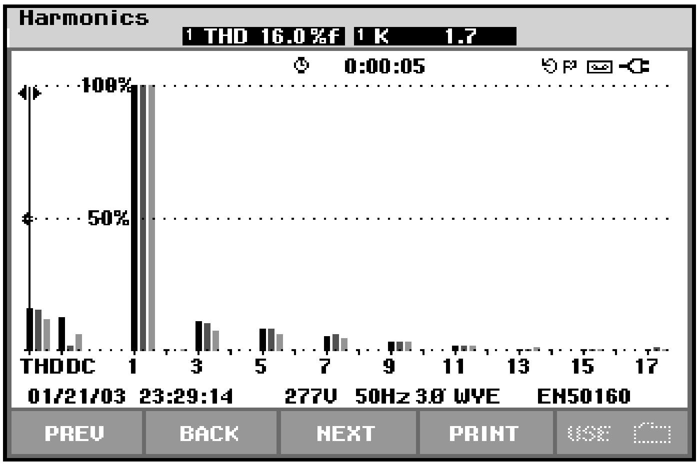

Figure 9: Harmonic component distribution at a THD of 14.57%.

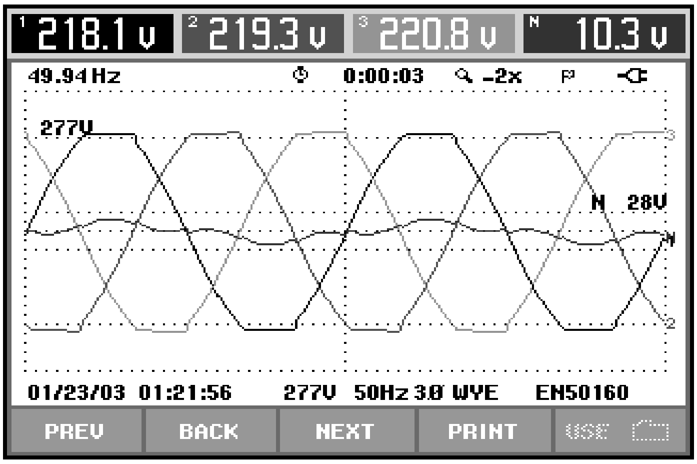

Figure 10: Line voltage waveform at a THD of 34.27%.

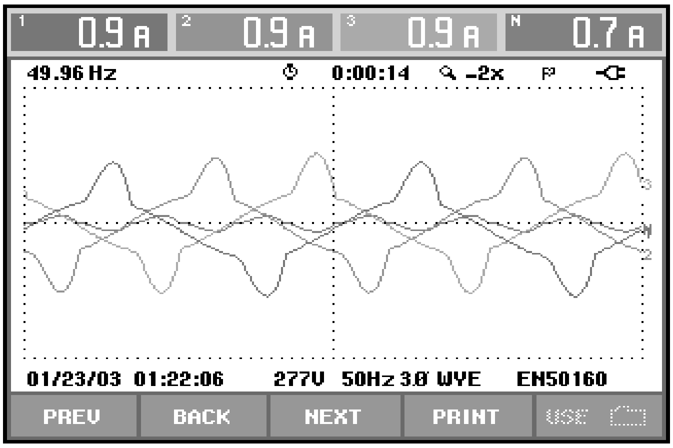

Figure 11: Line current waveform at a THD of 34.27%.

A plot of the transformer temperature versus time for each of the THD values is shown in Figure 12. Under constant load conditions, as the THD increased, an increase in the temperature of the transformer was observed.

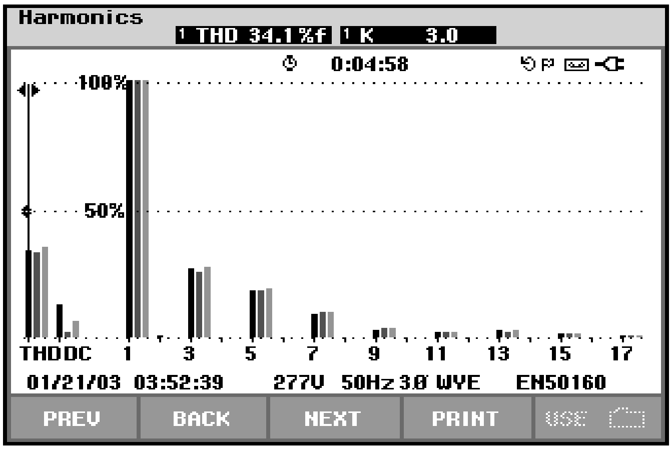

Figure 12: Harmonic component distribution at a THD of 34.27%.

For a rated transformer, abnormal increases in the heat content over long periods of time deteriorate the system, causing it to break down. This phenomenon is undesirable in power systems; thus, methods of preventing significant temperature changes must be developed. Specifically, the total load consumption can be reduced or a transformer with a higher rating can be employed.

From the data obtained in the present study, an approach to calculate the required reduction in the percentage of the total load consumption or the increase in the rating of a transformer was developed. As shown in Figure 12, when the THD was increased to 7.8%, the temperature of the transformer was 2.75% greater than the rated temperature. Thus, to supply the same load at a THD of 7.8%, the rating of the transformer should be increased to 102.75%. In this case, the actual rating of the transformer was 650 VA. Therefore, the transformer should be replaced with a 668-VA transformer to supply the same load and to prevent the 650-VA transformer from overheating. Similarly, when the THD was increased to 14.57%, the observed temperature increase was 5.90% greater than the rated value. Thus, to supply the desired load, a transformer with a rating of 688 VA should be used. Based on the same calculation method, for a THD of 34.27%, a transformer with a rating of 716 VA should be employed.

The calculations for the appropriate transformer rating are based on the assumption that the THD is linearly related to the temperature, which is proportional to the transformer rating. Therefore, one can assume that the THD is linearly related to the transformer rating. Using the data obtained in the present study, the percentage increase in the transformer rating was plotted, and the results are shown in Figure 13.

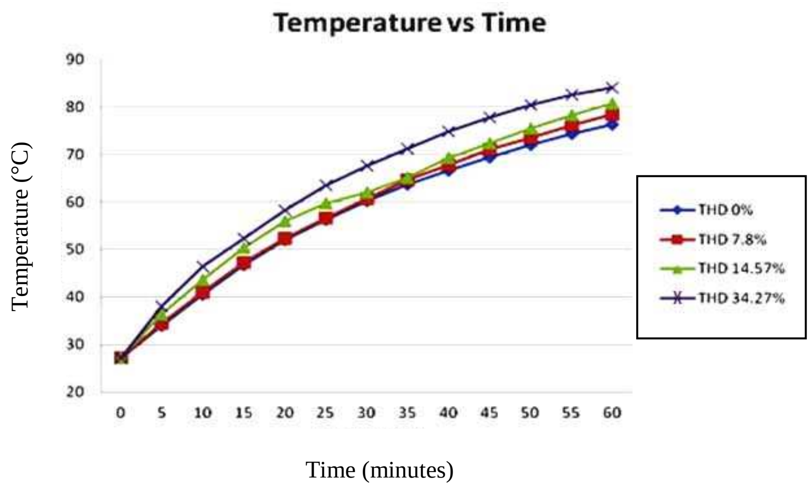

Figure 13: Graph of temperature vs. time for different THD values.

The proposed method is a practical approach for determining the rating of a transformer at different THD values under non-linear loads. From the graph shown in Figure 13, an equation relating the percentage increase in the rating of the transformer to the THD was derived:

$$\% T_R = 0.319\ (THD) \qquad (2)$$

where

$\% T_R$ = Percentage of increased transformer rating

THD = Percentage of load THD

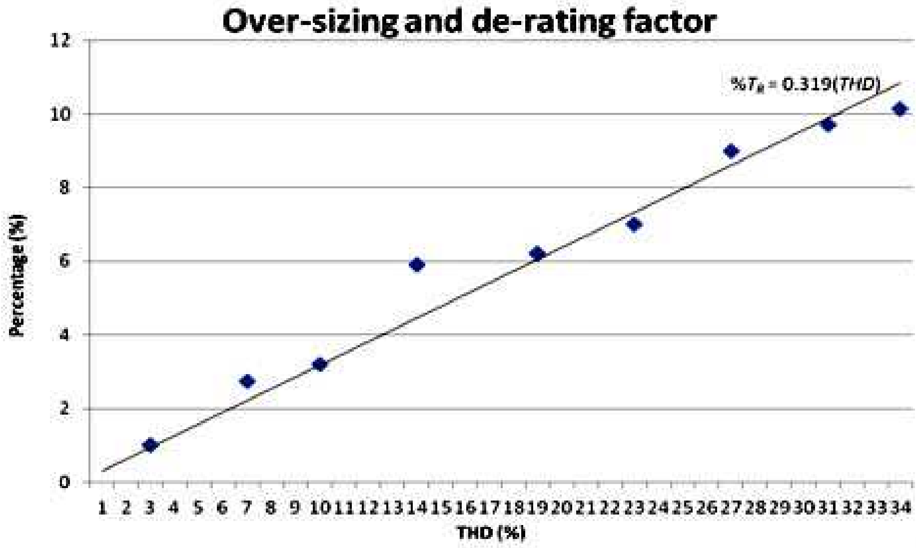

Figure 14: Graph of percent increase in the transformer rating.

If a transformer is used to supply a load that consists of harmonics, the transformer should not be operated under full load conditions and the load should be reduced according to the relationship shown in Figure 13. To use a 650-VA transformer and prevent additional heating, the power consumption of the total load should be reduced by 2.75% when the THD of the load is equal to 7.8%.

4. CONCLUSION

Due to the presence of harmonic components in non-linear loads, the temperature of the transformer increases under normal operations. In the present study, as the THD increased, an increase in the temperature of the transformer was observed. Namely, at a THD of 0% and 34.3%, the temperature of the transformer was 76.3°C, and 84.0°C, respectively. Using the results of the current investigation, the de-rating factor was calculated, and a value of 0.319 was obtained. Thus, a practical approach for selecting the appropriate transformer rating for specific operating conditions and THDs was developed.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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