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Analysis Magnetization Current of Harmonic Phenomena and Power Factor as Indicators of Core Saturation at Transformer 3-Phase

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Abstract

Saturation is a condition in which the magnets are fully transformer cores and generate maximum magnetic flux. Some parts affect the resilience and create distortions that can harm the heart. Core saturation can also increase the temperature and magnetization current transformer. In this study, we proposed a measurement method to obtain the necessary parameters to calculate a reliable indicator of the state of the transformer core saturation. The main effects of nonlinear flow in the transformer core are saturation, eddy current and hysteresis. In saturation, the core transformer is as a source of generating harmonic currents, some of which will flow directly to the primary and secondary windings. The method is based on the magnetization current, the phenomenon of harmonics and power factor is evaluated by measuring the no-load current at three-phase transformer, with a high magnetic flux density imposed. Measurements were taken at each phase of the transformer core. The transformer is connected to a variable voltage variable frequency (VVVF) as a voltage source and the investigation carried out at various flux densities. The results showed that the magnetization current and harmonic phenomena increased significantly when the high magnetic flux density and vice versa injected with power factor declined sharply. This phenomenon can be used as an indication of saturation of the 3-phase transformer core.

Keywords

Core Saturation, Magnetization Current, Harmonic

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1. Introduction

Construction of three-phase transformer is basically a single-phase transformer that is arranged into three pieces in the iron core. A transformer consists of a coil and an iron core. Usually there are two coils, namely the primary coil and the secondary coil. The two coils is not related physically but connected by a magnetic field [1].

By the standards of IEC (International Electro technical Commissioning) 1000.4 - 11, they're classified into harmonic interference waveform distortion [2] [3]. In this phenomenon changes the waveform of the wave base. Harmonics are sinusoidal voltage or current wave having a frequency which is the product of the integer (integer) of the fundamental frequency, wherein the supply system is designed to operate (typically 50 or 60 Hz). Basically harmonics are symptom formation of waves at different frequencies. It is called frequency harmonics arising from the original waveform, while integer multiplier fundamental frequency is called harmonics sequence number. Here is an example of a comparison of the basic waveform and harmonic wave [4] [5].

The level of disability in harmonics often expressed with Total Harmonic Distortion (THD), Total Harmonic Distortion, used as a gauge to see how much influence the overall presence of harmonics has to the sine signal. Because it is so large and varied effects of harmonics on equipment and systems are technical and economical, it is necessary to standardize the harmonics. Standards governing the harmonic distortion are the IEEE 512-1992 standard, this standard set of harmonics allowable limits (**Table 1**) [6].

Saturation is a condition in which the magnets are fully transformer cores and generate maximum magnetic flux. This usually happens if the transformer is not big enough for the application. While some parts affect the resilience and create distortions that can harm the heart. Core saturation can also increase the temperature and magnetization current transformer. In saturation, as the transformer core and current harmonics generation sources, some of it will flow directly to the primary and secondary windings. Results of previous studies show that the harmonic content increases significantly when the current no-load and high magnetic flux density injects. Today many transformers are widely disturbed by harmonics. Harmonic components have caused losses in the transformer which allows fails to operate.

2. Research Method

2.1. Material Research

Specifications transformer is used as the test material is as follows [8]:
The manufacturer: PT. Trafoindo Prima Perkasa
Type: Indoor
Power (s): 630 kVA
Number of phase: 3 phase
Impedance (Z): 4%
Cooling System: ONAN
Primary voltage: 20 KV
Secondary Voltage: 400/230 V
Core material: laminate M4 grain-oriented electrical steel (H1-Carlite)
Thickness of laminate: 0.27 mm thickness

Table 1. IEEE Standard 512-1992, harmonic current limitation [7].

| $I_{SC/L}$ | Maximum Harmonic Current Distortion in Percent of I_L | | | | | |
| | Individual Harmonic Order (Odd Harmonics) | | | | | |
	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

2.2. Measuring Instrument

Measurements were made with the simplest tool in measuring current and voltage that is ampere meter and voltmeter. Ampere meter used to measure the current value of the magnetization in the transformer. While the volt meter is used to measure the value of the voltage on the transformer. VVVF used as a voltage regulator and also the frequency at this time of measurement. Where the input voltage is connected with the core and frequencies connected to the secondary side of the transformer in **Figure 1**.

2.3. Circuit Testing

Testing is done by measuring the transformer core, where the ampere meter is connected to the input voltage and variable frequency (VVVF). On the secondary side of the transformer and on the primary side is connected to the VVVF and volt meter. Transformer testing lowered the ratio of 1.1. Measurements were performed with different flux density, which is done by varying the input voltage while the frequency is kept constant (fixed). Measurements were taken at each phase that is phase R, S, T, so that the measurement results has equal value or balanced on each phase. The series of measurements carried out as **Figure 2**.

2.4. Collect of Data

From the measurement results obtained: $I_1 = 0.00362\ \text{A}, I_2 = 0.0139\ \text{A}, \cdots, I_{19} = 1.622\ \text{A}$, then I_{rms} is as follows:

$$
\begin{aligned}
I_{rms} &= \sqrt{\sum_{h=1}^{\infty} I_{h,rms}^2} \\
&= \sqrt{I_1^2 + I_2^2 + I_3^2 + I_4^2 + \cdots + I_{19}^2} \\
&= \sqrt{0.00362^2 + 0.0139^2 + \cdots + 1.622^2} \\
&= 2.69136\ \text{A}
\end{aligned}
\tag{1}
$$

From the calculation $I_{rms} = 2.69136\ \text{A}$, the total harmonic current distortion (THDi) is as follows:

Figure 1. Sanwa PC 720 M digital multimeter and variable voltage variable frequency (VVVF) [1].
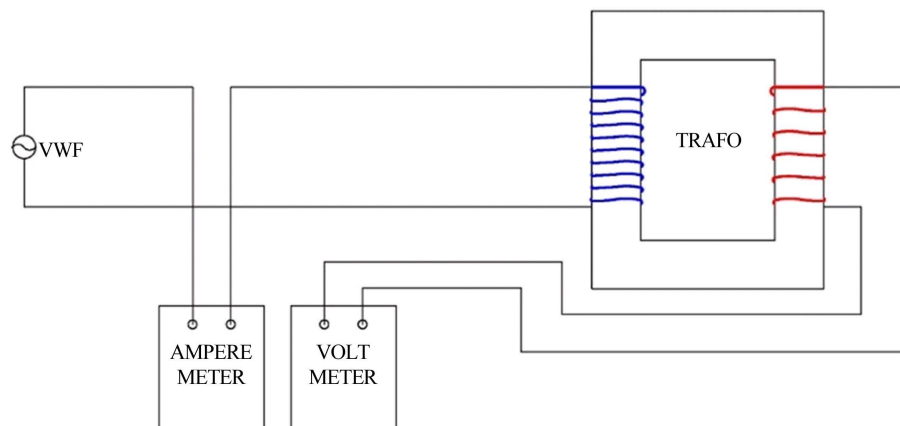
Figure 2. The measuring circuit transformer core [1].

$$\text{THDi} = \frac{\sqrt{\sum_{h=2}^{\infty} I_{h,rms}^2}}{I_{rms}} \times 100\%$$

$$= \frac{\sqrt{I_2^2}}{I_{rms}} \times 100\%$$

$$= \frac{\sqrt{0.0362^2}}{2.69136} \times 100\%$$

$$= 0.13\%$$

(2)

$$PF_{dist} = \frac{1}{\sqrt{1 + \left(\dfrac{THDi}{100\%}\right)}}$$

$$= \frac{1}{\sqrt{1 + \left(\dfrac{0.13\%}{100\%}\right)}}$$

$$= 0.99$$

(3)

3. Results and Discussion

The phenomenon of harmonics in this case distorted total harmonic currents (THD) and the magnetization current (Io) of the transformer in the magnetic flux density that varies at a frequency of 50 Hz shown in **Table 2**.

The relationship between the magnetization current and total harmonic current distortion (THDi) of the magnetic flux density at a frequency of 50 Hz is shown in **Figure 3** and **Figure 4**. While the curve of the power factor of the magnetic flux density is shown in **Figure 5**.

The evaluation results magnetization current (Io), total harmonic current distortion (THDi) and power factor are shown in **Table 2**. Stimulation magnetization current Io on the flux density B = 1.7 T (*i.e.*, Io = 0.95 A) almost doubled compared to 1.5 T (Io = 0.698). Meanwhile, THDi increases when the transformer that is charged with a magnetic flux density is higher. On the condition of flux density of 1.5 T and 1.7 T waveform is not sinusoidal currents that occur, as happened in **Figure 5**. While the flux density of 0.1 - 1.4 T shape of the current waveform is sinusoidal or perfect. This indicates that the flow has been distorted. Characterized by the core saturation current waveform is not sinusoidal or irregular.

Increased THD is very significant when a flux density of 1.5 T density change-1.9 T. This indicates that the core of transformer laminations experiencing burnout. **Figure 3** and **Figure 4** also shows that the pattern of Io and THDi the density flux density is almost the same with the B-H curve of a magnetic material. Besides saturation characterized by the value of the magnetic flux THD at 1.5 T with a value 25.93%. Where the value of THD
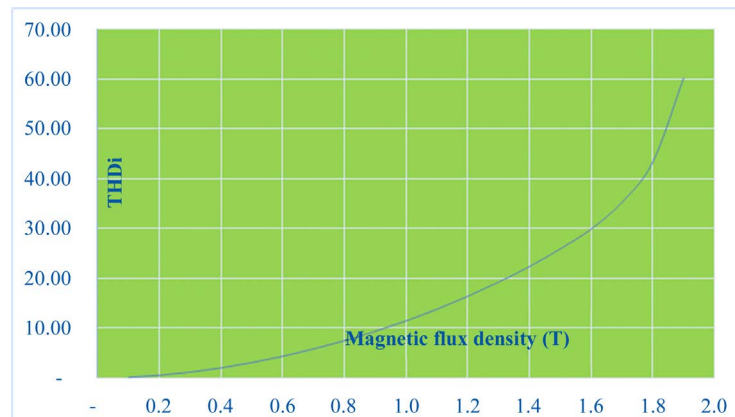
Figure 3. Curves total harmonic current distortion (%) of the magnetic flux density.
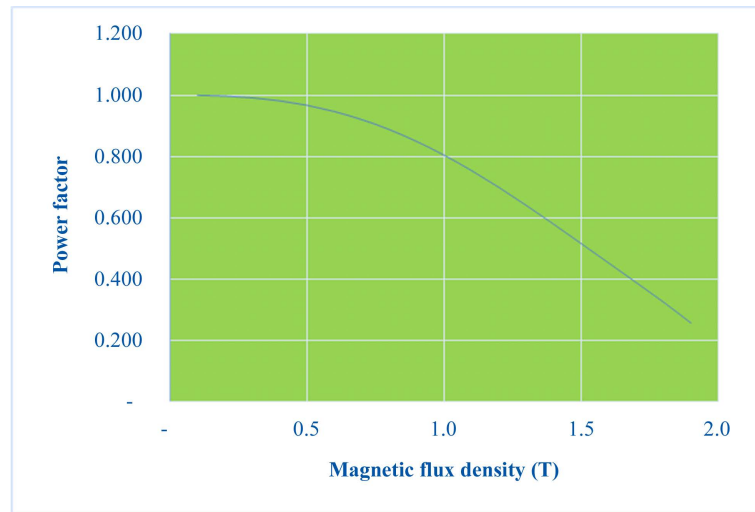
Figure 4. Power factor curve of the magnetic flux density.
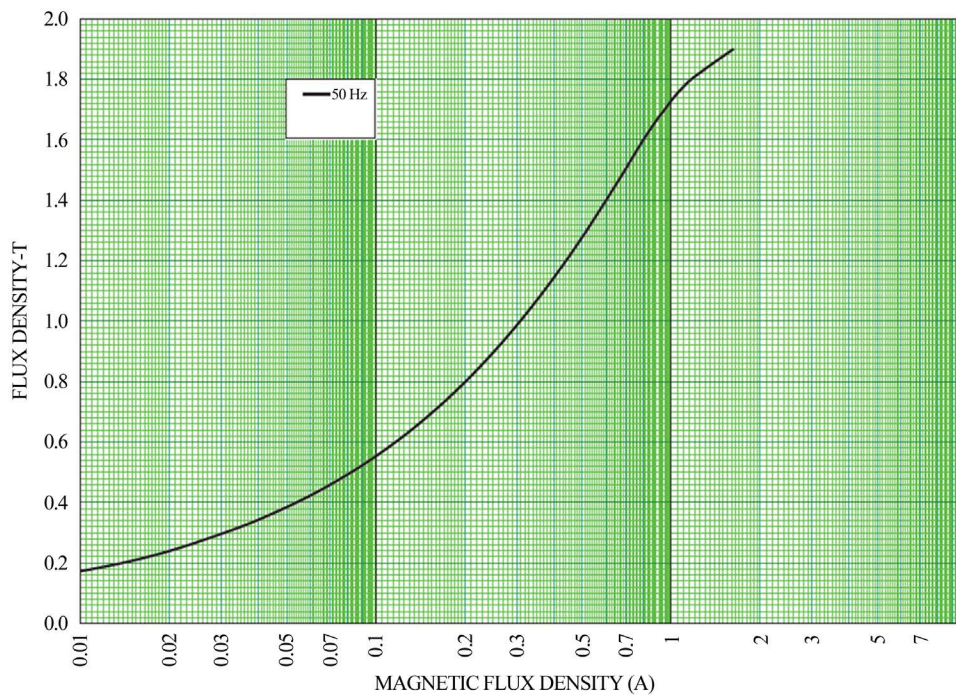
Figure 5. Magnetization current curve of the magnetic flux density.

allowable standards for electrical appliances maximum is 25% (IEEE 519-1992). As mentioned in Equation (7), the power factor is inversely proportional to THDi. This phenomenon is shown in **Table 2** or **Figure 4** It is clear that the power factor decreases significantly when a changing magnetic flux density of 1.5 T to 1.9 T. This can also be an indication that core transformer laminations have been experiencing burnout.

4. Conclusions

1) Analysis of the test data show a high magnetic flux density contributing more to the magnetization current, the phenomenon of high harmonics and power factor is low on the magnetic flux density that occurs in the normal operation of the actual transformer which is 1.5 Tesla or 1.7 Tesla.

2) The pattern of magnetization current and total harmonic distorted the magnetic flux density is almost the

Table 2. The calculation result THDi and power factor on the flux density that varies.

Flux Density (Tesla)	Io (Ampere)	THD (%)	Power Factor
0.1	0.00362	0.13	0.99
0.2	0.0139	0.52	0.99
0.3	0.0308	1.14	0.99
0.4	0.0539	2.00	0.98
0.5	0.0826	3.07	0.96
0.6	0.1168	4.34	0.94
0.7	0.1563	5.81	0.92
0.8	0.201	7.47	0.80
0.9	0.252	9.36	0.84
1.0	0.308	11.44	0.80
1.1	0.371	13.78	0.75
1.2	0.441	16.39	0.69
1.3	0.518	19.25	0.64
1.4	0.602	22.37	0.57
1.5	0.698	25.93	0.51
1.6	0.805	29.91	0.45
1.7	0.950	35.30	0.38
1.8	1.168	43.40	0.32
1.9	1.622	60.27	0.25

same as the curve B - H of the magnetic material (shown in the image above).

3) THDi of the transformer. When the 1.5 Tesla magnetic flux exceeds the standard IEEE 519-1992 *i.e.* 25% of the capacity of the transformer, then the transformer experiencing saturation condition is characterized by the onset of heat on the transformer.

4) This phenomenon can be used as an indicator to show that a 1.5 Tesla transformer core material has led to saturation.

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