Voltage - Current Waveforms Of Single-phase Power Transformer Due To DC Bias

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Abstract. The exist of direct current (DC) component in an alternating current (AC), known as DC bias (or DC Off-set) has undesirable effects, particularly on the power transformer, due to the problem of core saturation (half-cycle saturation). An investigation of magnetizing current waveforms of single-phase power transformer due to DC bias injection through MATLAB simulation is present in this paper. The simulation and study are done by injected AC and DC currents simultaneously. The value of AC is fixed and DC is adjusted (variable) in magnitude and also in the directions (positive and negative). The results show that the waveforms (displayed in magnetic flux) are distorted when the DC bias exists. The pulsated waveforms are pushed to half-cycle in the same direction as DC current injected (positive and negative half-cycle saturation). For comparative necessity, the result without DC bias is also provided.

1. Introduction

The core material of the transformer is made of high permeability material which is and useful for limiting and guiding the magnetic field lines that are formed inside the transformer. The magnetic field occurs due to the presence of a copper wire coil that is made in such a way as to surround the transformer core, then the copper wire is energized by an electric current [1].

DC bias also occurs due to electronic components [2,3] that produce additional flux in the transformer, causing the transformer core which was previously stable between the fluxes on the primary and secondary sides to become unstable [4]. The flux produced by the DC component will suppress the core flux in the transformer and make the transformer core saturated. As a result of that, the core is saturated for half-cycle so the DC bias current has the same direction as the magnetizing current in the transformer [5].

Because the DC component produces additional flux, that flux will change the alternating current (AC) flux waveform due to the biased DC flux that suppresses the flux at the core so that the alternating current (AC) that flux waveform will be more supportive towards the saturation direction on the positive side and the negative side. The condition of the transformer core that runs into this failure is called a half-cycle saturation. The transformer core material will run into a half-cycle saturation condition if the magnitude of the DC component is greater [4].
Figure 1. Excitation current and flux of power transformer with and without DC bias [4].

Explanation of Figure 1
Where
- \( N \) = number of turns
- \( \Phi_{AC} \) = AC flux produced by AC current (Volt-seconds)
- \( \Phi_{DC} \) = DC flux produced by the DC current (Volt-seconds)
- \( \Phi = \Phi_{AC} + \Phi_{DC} \) = total flux in the iron core (Volt-seconds)
- \( \Phi_s \) = saturation flux (Volt-seconds)
- \( \Theta \) = minimum angle in one cycle where \( \Phi = \Phi_s \)
- \( M \) = knee point
- \( N \) = saturation point
- \( I_s \) = current saturation (Ampere)
- \( I_{DC} \) = direct current due to DC bias (Ampere)
- \( k_1 \) and \( k_2 \) are gradients of piecewise magnetization characteristics.

As shown in Figure 1 that in without DC bias, the excitation current looks symmetrical against time, but when DC is biased, the excitation current becomes asymmetrical against time. At the same time, the DC current can produce DC fluxes so that the DC flux and AC flux in the transformer increase with each other. This condition is called half-cycle saturation in the transformer due to the effect of DC bias [6-7].

Power transformers generally only require a small amount of magnetizing current which leads to the knee point condition (M) look at Figure 1, so that only a small DC current can cause a half-cycle saturation condition in the transformer.

Figure 1 shows that the change in the excitation current in the transformer is taken effect if the DC current can change the direction of the flux in the transformer.

2. Experiment
In this study using an artificial single-phase power transformer that has 244 primary coils and 244 turns of the secondary coil as shown in Figures 2 and 3. Transformer core used is type m4 with dimensions of 306 mm, 508 mm (limb) and respectively, each 100 mm wide. The core of the m4 transformer is placed in the primary and secondary windings with acrylic laminate shown in Figure 4, the core thickness of 0.27 mm is arranged regularly the ends are overlapping 0.5 cm angular shape.
Figure 2. Coil of transformer

Figure 3. The primary and secondary coil

Figure 4. Transformer trainer (equipped with core lamination)

Figure 5 shows the circuit of experiments that have been carried out in this investigation. The primary coil of the transformer is connected to the secondary of an autotransformer, while on the secondary side of the transformer, the DC current source is injected through a half-wave rectifier and load to see its effect on the DC bias that arises based on the magnetic flux in the transformer. Investigations comparing the direction of the half-cycle saturation wave when the DC flux is biased and without the DC bias flux, the research was carried out by injecting DC currents which produced varying DC flux in Tesla.

Figure 5. Experiment circuit
3. Simulation

To plotting the image, the program will ask to enter the DC bias level. The value entered will be a shape of flux bias in the core. With the DC bias level set, the resulting bias flux on the B-H curve can be calculated [4] from equation (1).

\[ \Phi = \Phi_{AC} + \Phi_{DC} = \Phi_{max} \sin \omega t + \Phi_{DC} \]  

(1)

The simulation in this experiment uses the Matlab 2008 programs to allow the biased DC flux generated from an excited DC current and its direction as well. To be able to determine the flux density variation to be tested, it can be done by determining the primary voltage at a certain frequency. The formula that is used to determine the voltage [1,8-9] on the primary side is equation (2)

\[ E_{ind} = 4.44 \times B_{max} \times f \times A \times N \]  

(2)

Where

- N = number of turns
- f = supply frequency (Hertz)
- Bmax = maximum magnetic flux density in the core (Tesla)
- A = Effective core area (m2)

so,

\[ A = n \times w \times t \]  

(3)

With

- n = number of layers of core lamination (35 layers)
- w = width of the core in meters (in this case 100 mm = 10^{-1} m)
- t = thickness of core lamination in meters (in this case 0.27 mm = 27 \times 10^{-5} m)

then by varying the input voltage, the magnetic flux density can also be varied.

4. Result and Discussion

By doing this experiment, the flux waveform that shifts in the transformer core can be observed according to the magnitude of the effect of DC bias that occurs.

4.1. Magnetic Flux Density versus time without and with DC Bias

The flux density produced from the m4 type transformer core can be seen in Figure 6 which has been plotted with the Matlab application in conditions without DC bias, there is no half-cycle saturation in this condition, the shape of the wave density flux is symmetrical to the positive and negative sides, both of which have peaks that are the same, which has the same value, namely 2 Tesla in this condition, there is no need to make observations because there is no half-cycle saturation.
When the induced DC flux is 0.2 Tesla with a maximum flux of 2 Tesla in the transformer and plotted with the Matlab program it can be seen in Figure 7.a, showing the characteristics of the flux density by the time, in Figure (7.b, 7.c and 7.d) can be seen as the characteristics of the flux density with time with different DC bias values.
The symmetrical waveform being pushed towards the point of saturation is very clear, there is a DC bias pushing it from the normal cycle towards the saturation direction. The positive cycle has been pushed to a saturation point (2 Tesla). Whereas on the negative side the DC bias flux has shifted the negative cycle from its saturation point to the positive.

![Figure 7.c Waveform with DC bias 0.6 Tesla](image1)

![Figure 7.d Waveform with DC bias 1.0 Tesla](image2)

**Figure 7.** Flux Density versus Time characteristic with different DC bias

**4.2 Magnetizing Current without and with DC Bias**

Can be seen in figure 8, the B-H curve without DC bias has a symmetrical shape, the magnetization current has an asymmetrical shape about the horizontal axis as shown.
The shape of the B-H curve is asymmetrical because the magnetic field currents are not symmetrical due to the large magnetic field, H is a function of the magnetizing current if the magnetic currents are plotted against time, distortion can be seen clearly.

To see the injected DC bias value of 0.2 Tesla against the 2 Tesla value that is at the maximum flux built into the transformer, the plot of magnetization current against time can be seen in Figure 9.a, to see its characteristics of magnetizing current against time with a different value of DC flux densities (0.4 Tesla to 1.0 Tesla), can be seen in Figures 9, b to 9, d.
Figure 9 shows, it only takes an instant that the peak of the magnetization current is at 6.4866 A, but the peak of the negative magnetization current is -0.85479 A, saturated for half-cycles, the waveform of the magnetization current becomes nonlinear due to the magnetizing current at first small rises to large. Due to the fact that the permeability of the core changes with the instantaneous value of the driving current, the actuating current or magnetization is not truly sinusoidal.

5. Conclusion
Based on the experiments that have been carried out by varying the caused DC flux density, it can be seen that DC bias currents can cause half-cycle saturation in the transformer and the direction (positive and negative) of DC bias which suppresses the built-in flux in the transformer. When the core enters half-cycle saturation, it draws a large magnetizing current, which is directly proportional to the injected DC flux value, when the injected bias DC value is greater, the greater the value of the magnetizing current on the positive cycle. However, the flux density in the negative cycle has a smaller value (towards a more positive value). Under the influence of half-cycle saturation, the magnetizing current shows an asymmetric characteristic.

The transformer plays an important role in quality and lifetime. The use of a transformer according to the load supplied by the transformer.

6. References
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