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ANALYSIS THE EFFECT OF DC BIAS ON A THREE PHASE THREE LIMB TRANSFORMERS THROUGH FEM TECHNIQUE

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Abstract: This article creates a system based on the Finite Element Method (FEM) to comprehend how DC currents affect the transformer's operation. Analysis is done on harmonic development and its effects on the magnetic field. The scaled transformer model is created with ANSYS software, and MATLAB is used to display the findings. The results demonstrate that when the transformer is subjected to various degrees of growing primary voltage and adding DC bias to the model of varying magnitude, odd harmonics occur based on the saturation condition of the transformer. Due to the structural design of a three-phase, three-limb transformer, even harmonics are not seen since they have a high resistance to DC flux. Additionally, it is emphasised that flux leaving the results depending on the amount of DC fed, both the transformer core and its saturation level might vary significantly.
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Keywords: Three phase threre limb transformer, Saturation of Tensformer, DC Bias , Half cycle core Stauration, Injection of DC, GICs

Introduction:

Power transformer cores are typically operated with alternating current (AC) fields, therefore they are built to carry AC current. However, the presence of a superimposed DC flux over an AC flux can quickly cause the transformer to saturate, harming the transformer's internal components. The transformer has a propensity to saturate during a DC half-cycle as the magnetising current shifts in a positive direction due to a unidirectional DC flux in the core. This phenomenon is known as half cycle saturation [1] and is widely the main effect of DC superimposed over AC flux in transformer. Given enough time for the currents to multiply by the number of winding turns, even a tiny quantity of direct current (DC) can generate a significant amount of magnetic flux (MMF) inside the core. The production of harmonics and increased demand for reactive power result from the increase in losses, which also negatively affects the transformer's structural components by causing overheating in a number of places, including the tank wall, tie plates, and clamping plates. The increase in losses, particularly the core losses and stray losses, also has a negative impact on the transformer. The main source of DC injection into the power transformer is the geo-magnetically induced currents (Geo-magnetically Induced Currents (GIC)) [2]-[5] are produced by the combination of magnetic field of earth and solar winds. Other DC sources include HVDC transmission cables and power electronics devices like the anti-parallel thyristor configuration. Neutral offset from DC drives is another potential source. The odd and even harmonics [6]-[8] produced as a result of DC magnetization causes increase in the stray losses and sometimes false tripping in power system.

Three Limb Transformer Construction & Superimposition of DC flux:

When building a three-limb transformer, the three legs or limbs are each wound with a Cu coil to represent one of the transformer's three phases. There are two yoke structures at the top and bottom of the structure because each limb is connected to yokes on either side of that limb. Thus, linking the limbs and yokes completes a transformer flux route. A flux flows through each limb of the transformer under normal working conditions, and because the source is alternating and sinusoidal, the flux is also flowing and is almost equal in the limbs and the yoke. The flux opposes and cancels in the transformer's yoke area when the three phase transformer is in a balanced state, so there is no need for a flux return path. This is not the case, though, for an unbalanced load when the full flux must go across a wider air gap before returning to the core once more. It is intriguing to observe the effects of this extremely high reluctance path on the transformer flux when it is superimposed with a DC flux since this vast air gap area gives a very high reluctance for the flux to travel through. The regularly produced flux varies as the DC flux is superimposed onto the typically generated AC flux; this flux is now a unidirectional DC flux, which depends on the resistance provided to the DC flux channel, the number of turns in the windings, and the amplitude of the DC. A complete sinusoid's dc flux would be added in one half of the cycle and subtracted in the other, resulting in a flux shift. The excitation current in the positive direction increases noticeably as the average flux starts to rise in the direction of the shift, increasing the saturation in the positive direction as well. The excitation current becomes significantly positive when the flux keeps growing and becomes big enough to diminish the excitation current in the negative half cycle. As a result, the transformer's core experiences partial magnetic saturation, which prevents it from operating at its predicted working point. Because of the extremely high peak flux densities in the magnetic core during one half of the cycle, it is non-linear to display the B-H curve. Due to the increased reluctance provided by the core material, it is possible to visualise a smaller shift in the flux density, and consequently, the magnetising currents reach higher peaks and last for a shorter time.

Modelling Mechanism

The Finite Element Method (FEM) is the simulation technique used to simulate the scaled transformer [9]–[10]. This method offers a numerical solution to the boundary conditions that are connected to each transformer based on the flux at various core locations. With the aid of this technique, it is possible to anticipate which sections of the core will be significantly damaged by the injection of DC current on the transformers [11]. An ANSYS model of a scaled transformer is shown in Fig.1.1.

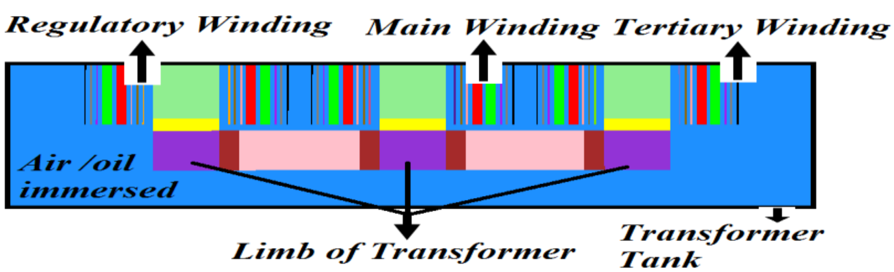


Fig.1.1. Two dimensional Three-Phase Three-Limb transformers FE Model

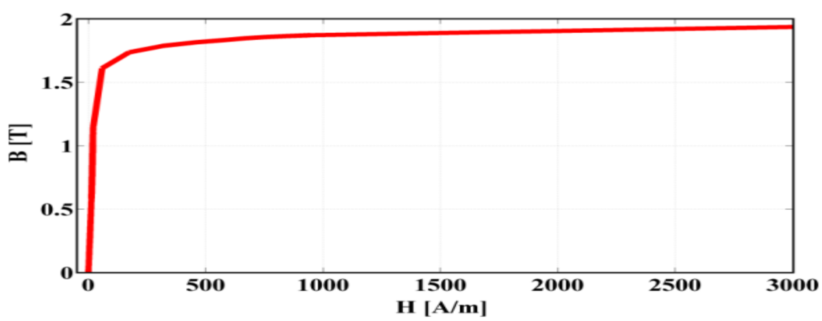
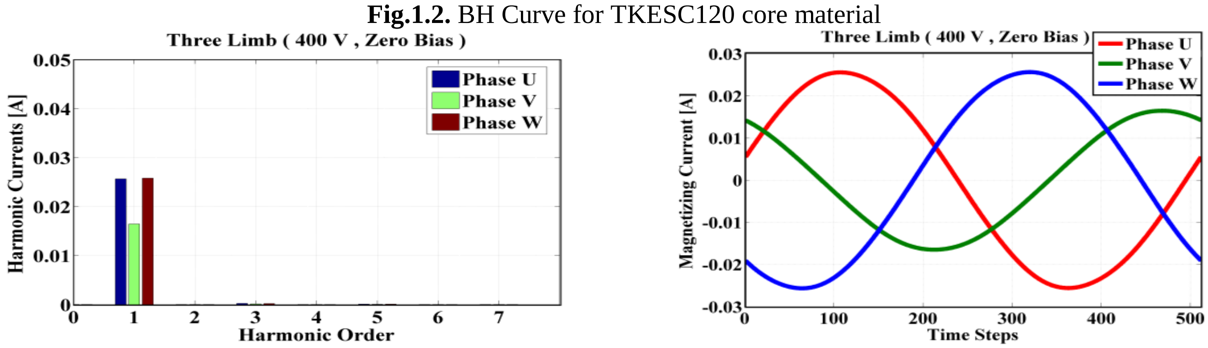
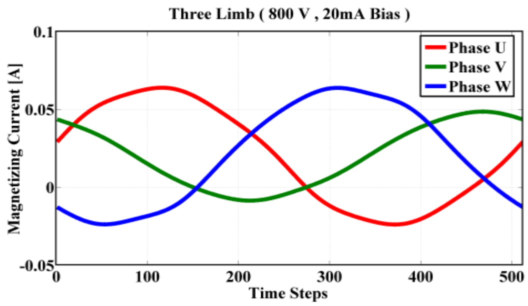


Fig.1.2. BH Curve for TKESC120 core material

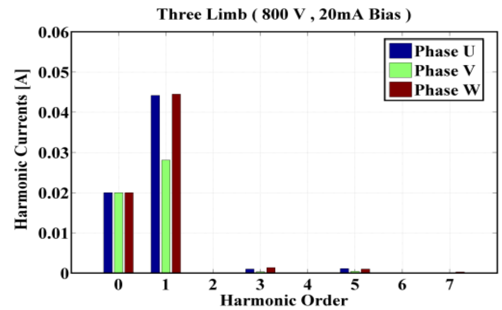


(a)
(b)

Fig.1.3. (a) Magnetizing Currents (b) Harmonics at Zero (0) DC Bias

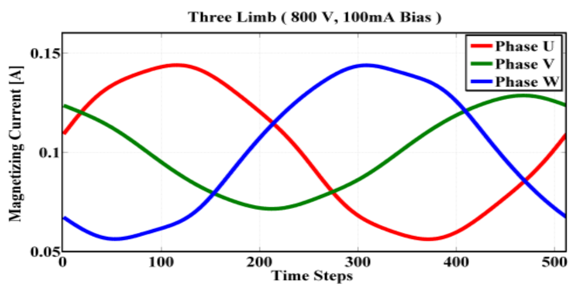


(b)



(a)

Fig.1.4 (a) Magnetizing Currents (b) Harmonics at [Input Primary Voltage=800V, 20mA DC Bias]



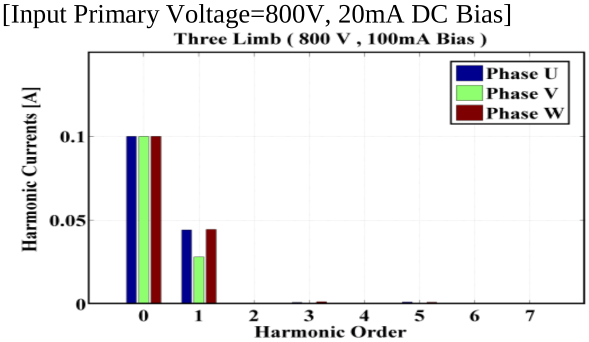
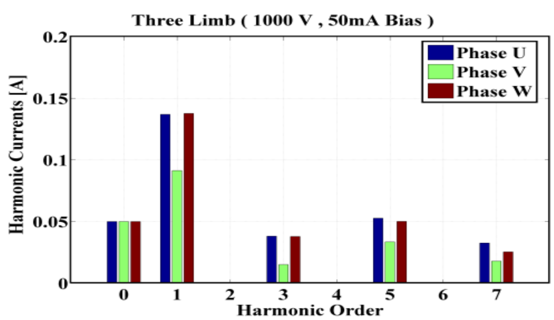


Fig.1.5 (a) Magnetizing Currents (b) Harmonics at [Input Primary Voltage=800V, 100mA DC Bias]



(a)
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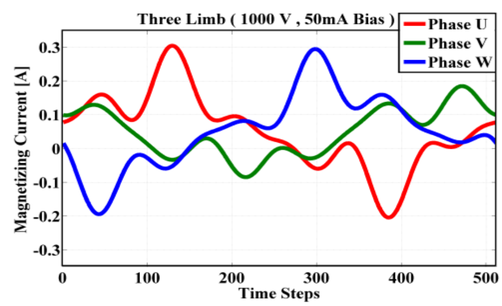

Fig.1.6 (a) Magnetizing Currents (b) Harmonics at [Input Primary Voltage=1000V, 50mA DC Bias]

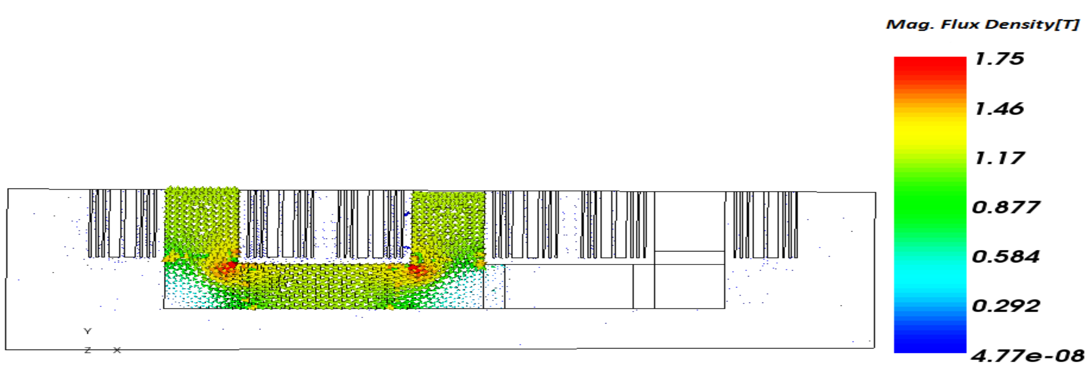

Fig.1.7. Flux Distribution in Transformer Without DC [Zero or 0] bias

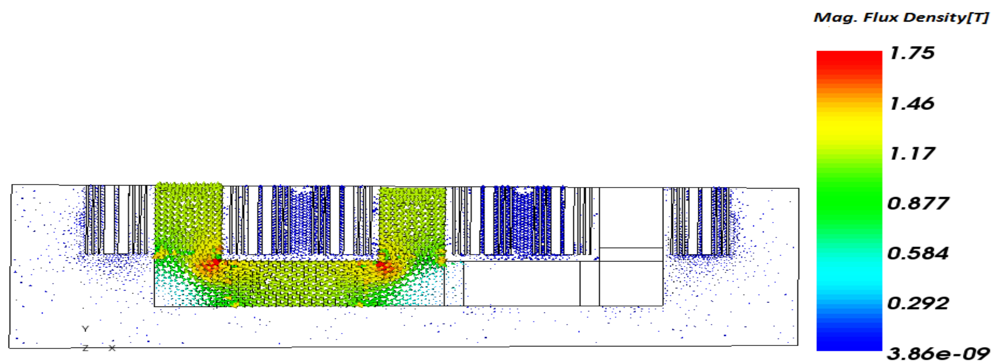

Fig.1.8. Flux Distribution in Tra nsformer With 75mA bias

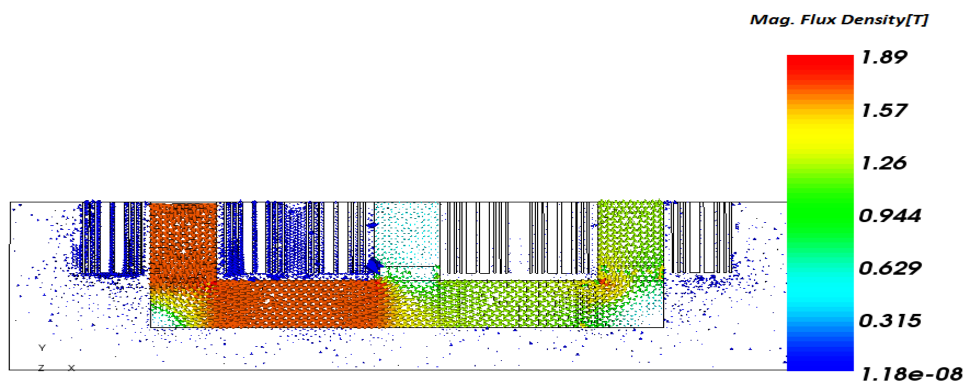

Fig.1.9. Flux Distribution with DC bias of 1A

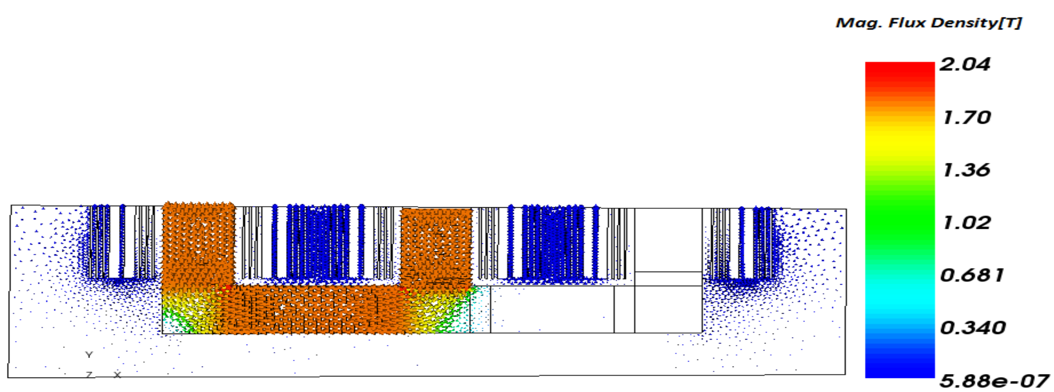

Fig.1.10. Flux Distribution with DC bias of 2A

Working Point Calculation Of Transformer Considering Non Linear Material Properties

Transformers working point is more justifiable if the non-linear properties of the core material are considered. The material of the core will be represented by effective B-H characteristics. Using a weakly coupled multi harmonic [12]-[14] approach the results of the Finite element is transformed for further analysis in frequency domain and it is understandable to get the harmonics in this domain which is suitable for the evaluation of DC injection.To calculate the working point of a transformer for non linear material requires more computational efforts compared to a linear material. Begin with the linear materials and finally end up calculating the exciting currents and vector potential solutions for flux calculations and visualization of the transformer non linear core material. The idea behind calculating the working point for a non-linear core material is to reach to an operating point in the B-H curve, which is close to the saturation level of the transformer and later see the impact of DC at these operating points. Thus, considering a core reluctivity for the transformer at its rated flux density initially a linear inductance matrix is calculated and then the fundamental component of the transformer currents are obtained and converted into time domain and later calculating the nonlinear inductance matrix at different time steps considering non linear properties of the selected material. Further from the non-linear inductance's and the flux obtained the magnetizing currents for the non linear materials in the frequency domain are calculated by taking the Fast Fourier transform to visualize the harmonics in the currents. To obtain the impact of DC for the nonlinear core material a DC component is injected as different percentage of a fundamental current after and the Fast Fourier transform (FFT) is calculated to visualize the impact on the magnetizing currents and the harmonics

Simulation Results for Scaled Transformer Model

The transformer model has the 3 phase 3-limb having 8 coils on each limb. With 2 coils as main winding, 1 coil as the tertiary winding and remaining 5 coils as the regulating windings. The technical details of the transformer are given in the Table 1.1.

Table 1.1. Technical Detail of Transformer

Sr. No	Parameters of Transformer	Value
1	Rated Power	6.9 kVA
2	Rated voltage	400/400 V
3	Rated current	10/10 A
4	Rated frequency	50 Hz
5	Rated flux density	1.2T
6	Switching group	Adjustable

When a transformer saturates, the whole core usually does not saturate on the same level. That is, part of the core may saturate more than other parts, while some part may not saturate at all. The core saturation patterns may vary depending on the core configurations. The flux distribution and the magnetizing current calculation are done based on the working point calculation considering non linear material properties as discussed for the no load case. The non linear core material considered for the scaled transformer is TKES C120 with a peak flux density at saturation near to 1.7 T as shown by the B-H Curve in the Fig.1.2.

While injecting the DC into the model, it has been taken as some percentage of the fundamental current initially injecting a lower percentage of the fundamental component and then higher to visualize the differences. The primary winding has been also excited at different levels of voltage to see the impact of DC close to the saturation point of the transformer. The windings are connected in star and the neutral is grounded. The results are plotted in MATLAB in a two way pattern so as to analyze the magnetizing current behavior and the harmonic content measured for in the non-linear core material with the impact of DC.

Results Interpretation of DC Impact On Magnetizing Currents and Harmonics

It is observed that as the level of DC bias increases in the transformer core with non linear material a small increase in the odd order harmonics based on the saturation level of the transformer (see Fig.1.3 to Fig.1.6). But there is no effect on the even harmonics. This can be attributed to the fact that DC flux in case of a the three phase three limb transformer design is obstructed by magnetic reluctance which is very high and that flux passing through the core-tank magnetic circuit has a zero flux path, but while considering the 2D Model this flux path is not considered and hence DC flux leaves as stray flux. Because the magnetizing currents depend on the total flux and since the DC flux has no impact owing to absence of zero flux path there is no increase in even order harmonics and hence for a particular voltage level the magnetizing current remains the same with the absence of even harmonics. Visualizing Flux And Magnetic Vector Potential For an input primary voltage of 800V in ANSYS it is visualized the stray fluxes which are leaving the transformer core and see how the saturation level of the flux changes with DC bias of 75mA as shown in Fig.1.7 and Fig.1.8. It is observed that the influence of stray fluxes is higher with DC bias when the DC flux is superimposed with the alternating flux. Also a comparison can be made between two different DC levels for a transformer core applied with a primary voltage of 1200V from Fig.1.9 and Fig.1.10 which depicts the increase in saturation flux by the magnetic flux density scalar bar with a higher level of DC current of 2A compared to 1A.

Conclusion

On the impact of DC on the three phase three limb transformer, it is visualized that based on the saturation levels and the core structure of a three leg transformer the odd harmonics are visible and increases as the saturation level increases but there is no influence on even harmonics owning to the high reluctance path the 2D model offers. Also the ANSYS results depict an increase in stray fluxes and a higher saturation level with peak flux densities at a higher level of DC.

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References:

[1]. Ngnegueu T., Marketos F., Devaux F., Xu T., Bardsley R., Barker S., Baldauf J., Oliveira J.: Behavior of transformers under DC/GIC excitation: Phenomenon, Impact on design/design evaluation process and Modeling aspects in support of Design. Cigre (2012).
[2]. Vassell G. S.: Northeast blackout of 1965. IEEE Power Engineering Review, ISSN: 0272-1724, January (1991).
[3]. Price P. R.: Geo-magnetically Induced Current Effects on Transformers. IEEE Transaction on power delivery, Vol. 17, Issue 4, pp. 1002-1008, Oct (2002).
[4]. Kappenman J. G.: Geomagnetic Storms and Their Impact on Power Systems. IEEE Power Engineering Review, ISSN: 0272-1724, May (1996).
[5]. Girgis R., Vedante K.: Effects of GIC on Power Transformers and Power Systems. IEEE Transmission and Distribution Conference and Exposition (T&D), IEEE PES, pp. 1-8, May (2012).
[6]. Xu W., Martinich T. G., Sawada J. H., Mansour Y.: Harmonics from SVC Transformer saturation with Direct Current Offset. IEEE Transactions on Power Delivery, Vol. 9, Issue 3, pp. 1502-1509, ISSN: 0885-8977, Jul (1994).
[7]. Yarnada S., Bessho K., Lu, J.: Harmonic Balance Finite element method applied to nonlinear AC magnetic analysis. IEEE Transactions on Magnetics, vol. 25, Issue 4, pp. 2971-2973, ISSN: 0018-9464, Jul (1989).
[8]. Lu S., Liu Y., De La Ree J.: Harmonics generated from a DC biased transformer. IEEE Transactions on Power Delivery, vol. 8, Issue 2, pp. 725-731, ISSN: 0885-8977, Apr. (1993).
[9]. Zhao X., Li Lin, Lu Junwei, Cheng Z., Lu T.: Characteristics Analysis of the Square Laminated Core under dc-biased Magnetization by the Fixed-point Harmonic-balanced FEM. IEEE Transactions on Magnetics, vol. 48, Issue 2, pp. 747-750, ISSN: 0018-9464, Feb. (2012).
[10]. Lu S., Liu Y.: FEM Analysis of DC saturation to assess transformer susceptibility to Geo-magnetically induced current. IEEE Transactions on Power Delivery, vol. 8, Issue 3, pp. 1367-1376, ISSN: 0885-8977, Jul. (1993).
[11]. Fuchs E. F., You Y., Roesler D. J.: Modeling and Simulation, and Their Validation of Three-phase Transformers with Three Legs Under DC Bias. IEEE Transactions on Power Delivery, vol. 14, Issue 2, pp.443-449, ISSN: 0885-8977. Apr. (1999).
[12]. Yamada S., Bessho K., Lu J.: Harmonic balance finite element method applied to non linear AC magnetic analysis. IEEE Transaction on magnetic, vol. 25, Issue: 4, pp. 2971-2973, Issue 0018-9464, Jul (1989).
[13]. Björn R., Adalbert L. E., Kay H.: Calculation of the flux distribution of three phase five limb power transformers considering nonlinear material properties. International Journal for Computation and mathematics in electrical and electronics engineering, vol.32, Issue 4, ISSN: 0332-1649., (2013).
[14]. Björn R., Kay H.: Multi Harmonic approach to determine load dependent local flux variations in Power transformer core. Archieve of Electrical Engineering, vol. 64, ISSUE: 1, pp. 129-138, (2015).

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