Partial Discharge Pattern Analysis of Palm Oil for Optimized Transformer Insulation Applications

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Abstract- Insulation of the transformer is the most important thing to resist the flow of current. Typical insulation of solid and the liquids are used in the transformer to dissipate the heat energy and provide the coolant service to the transformers. In previous years, the mineral oils are used for this purpose, and now a days those materials are converted into the vegetable oils which can provide the sufficient insulation to the transformers. In this paper "partial discharge pattern analysis of palm oil for optimized transformer insulation applications", the palm-based oils are used as a dielectric material. The design procedures include the rectangular ultra-wide band magnetic core Tesla transformer, in which the coupling coefficient has become the popular one, it can be obtained through the elephant herding optimization algorithm being this two update vectors are processed. The iteration process can yield the optimal value which is attained for the coupling ratio. At the load of the transformer the electrical characteristics of "partial discharge test" is carried out, in which the excessive voltage beyond the threshold limit can cause the breakdown. This can be prevented under the test. The experimental results are carried out on the MATLAB/SIMULINK. Finally the comparison results are carried out over the recent papers which are mentioned in the references. Those papers obtained the less efficiency when compared with our proposed approach.

Key words: rectangular ultra-wideband magnetic core tesla transformer; palm oil; partial discharge test; elephant herding optimization algorithm.

1. Introduction

One of the luxurious component of the power transformer occurs the breakdown by this the liquid insulation performance is degraded. The demerits of the conventional mineral oils have been conducted by the previous research workers. Those performance are overcome through the natural ester based transformers, these are easily available and biodegradable. The dielectric characteristics of various oils such as corn oil, coconut oil, castor oil, olive oil, and the palm oils are already reported [1-2].

The transformer is designed with the magnetic cores, which is formed due to the windings of the transformer. In primary side, the windings and the capacitors are connected in series due to this the primary circuit is formed. Similar the coaxial capacitor, and the secondary windings can form the secondary circuit [3]. The transformer characteristics are associated with the properties of magnetic core. The poor performance are obtained due to its small structure, magnetic saturation, and core losses. These kinds are proportional to their operating frequency [4].

In power system, most of the transformers are oil filled type and it may act as an insulation system. The oils can withstand at different potentials [5-8].The characteristics of the palm oils are nearly close to the characteristics of the natural ester based oils and it is nontoxic [9-11].The chemical reactions are caused among the oxygen and these oxidation reactions can increase the rate of oil and the paper ageing [12]

Commercially available palm oil is used as a basefluid and its properties are listed in table 1. At the start,palm oil sample was placed in a sealed steel container andthermal treatment was done at 60°C for 24 hours inside atemperature controlled oven in order to remove moisturecontent and then the sample was allowed to cool to roomtemperature for 24 hours [13-15].Palm oil has better insulationcharacteristics comparable with mineral oil Hence development of Nano modified palm oil with enhancedinsulation performance will be useful for electrical utilities.Partial discharge (PD) is one of the major sources ofinsulation performance degradation of transformer oil. The recent relevant techniques are mentioned in the literature survey.

The organization structure of the paper defines the problem formulation is makes under the section of 4, the proposed methodology is defines in section 5, and the results are discussed in section6.

2. Literature review

S.No	Authors	Description	Demerits
1	Shriram RA *et al* [16]	• The confidence level of the power transformer is highly improved by SiO2 nano-fillers in palm oil. • Inception voltage, PD signal time-frequency domain characteristics, PD signal equivalent time length-bandwidth mapping, repetition rate and phase angle variations are evaluated at different test conditions.	• Low level of partial discharge.
2	Azis N *et al* [17]	• Mineral oil has been widely used as dielectric insulating fluid in transformers due to its excellent performance in-service. • Palm basedoil as dielectric insulating fluid in transformers is carriedout.	• Poor degradability of mineral oil
3	Senthilkumar S et al [18]	• PD signals were measured using wide band detection system. • Time and frequency domain analysis of PD pulses at needle-planeelectrode configuration was carried out.	• Low performance

3. Objectives

The research objectives in this work is as follows,

- Design the rectangular ultra-wide band magnetic core tesla transformer it is shown in Figure. 1.
- To tune the coupling coefficient ratio through the Elephant herding optimization algorithm.
- Improve the confidence level of the transformer through the partial discharge test.

4. Problem formulation

Insulation for power transformer is the hot research topic recently. Most of the research workers had been established the dielectric properties of mineral oils (Petroleum, natural ester based oils). Most of the insulation characteristics are presence in the Palm oil when compared with the mineral oils. The major drawbacks in the existing are the low level of partial discharge. It is the major concern why because, when the increased level of the partial discharge (PD) can improve the insulation characteristics of the transformer oil. The ultra-wideband electromagnetic source can prefer the magnetic core tesla transformer, in which the magnetic core may be in cylindrical, rectangular. The drawbacks of the existing works are degraded by the proposed methodology.

The magnetic field strength is proportional to the closeness of the lines (Lines per unit area perpendicular to the lines). The magnetic fields of the magnetic cores and the spacing of the lines are closely given as,
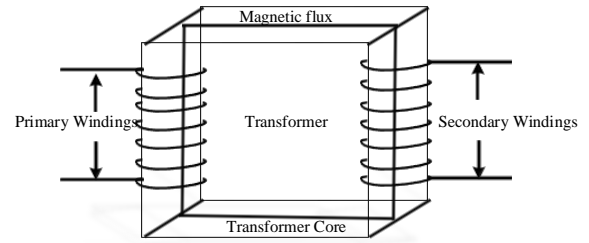

Figure 1. Magnetic core tesla transformer

$$h_1 = h_{11} = h_{12} \tag{1}$$

$$h_2 = h_{21} = h_{22} \tag{2}$$

Where the terms of h_1, h_{11} and h_{12} are the magnetic cores, and the spacing among the magnetic cores are given as h_2, h_{21} and h_{22}.

4.1. Flux Conservation

The transformer cannot deserve the power immediately due to the presence of losses in the transmission system, but it can conserve the power indirectly. The line current was reduced by the boost up of transmission voltage. The lower line current can cause the less amount of power losses, so this can conserve more amount of power. The flux depends on the effective cross sectional area (a_e), while continuing this process, the flux conservations of primary ($\varphi 1$) and the secondary ($\varphi 2$) terms are presented by,

$$\varphi 1 = a_e h_1 \tag{3}$$

$$\varphi 2 = a_e h_2 (s) \tag{4}$$

The radius of the magnetic cores are lies within the interval of inner (s_j) to outer (s_0), and it is mentioned by,

$$s_j \leq s \leq s_0 \qquad (5)$$

Relationship between the magnetic cores

$$\mu_s a_e h_1 = s h_2(s) \pi (L_t - L_k) \qquad (6)$$

The magnetic core relationship have been mentioned in (6), where the magnetic core length is to be L_t, and primary secondary windings overlap length is to be (L_k). The radius of the magnetic core is to be (s).

Ampere's circuital law

$$h_1 L_t + h_2 s_j \, ln \, \alpha \pi = \frac{1}{2} n_1 \times I_1 \qquad (7)$$

Where $\alpha = \dfrac{s_0}{s_j} \qquad (8)$

The dielectric strength of the secondary capacitor is α.

4.2. Relationship between the storage energy in magnetic cores and spacing

The storage energy in the magnetic core and the storage energy in the spacing are mentioned below, from which the relative permeability (μ_s), and the permeability of free space is (μ_0).

$$\frac{E_1}{E_2} = \frac{\frac{1}{2} \int \mu_s h_1^2 \partial v}{\frac{1}{2} \int \mu_0 h_2^2 \partial v} \qquad (9)$$

$$\Rightarrow \frac{\pi L_t (L_t - L_k)}{\mu_s a_e \, ln \, \alpha} \qquad (10)$$

4.3. Magnetization inductance

$$M_\mu = \frac{1}{I^2} \int B \times h \partial v \qquad (11)$$

$$\Rightarrow \frac{\pi}{2} n_1^2 \frac{(L_t - L_k)}{ln \, \alpha} \qquad (12)$$

Where $L_t = \dfrac{\varsigma \times d}{\sqrt[2]{\varepsilon_r}} \qquad (13)$

In above equation (13), the dielectric constant of the insulating material is (ε_r), light velocity is (d), and the pulse width (ς). The magnetization inductance is (M_μ).

$$L_k = \frac{L_t}{2} \qquad (14)$$

4.4. Leakage Inductance

$$L_\mu = \frac{1}{I^2} \int (h_{prim} - h_{sec}) \partial v \qquad (15)$$

$$\Rightarrow \frac{\pi}{3} n_1^2 \frac{s_0^2 (\alpha - 1)(2\alpha - 1)}{L_C \alpha^2}$$

The primary and the secondary magnetic fields are h_{prim}, and h_{sec} respectively. The leakage inductance of the coils are L_μ.

4.5. Coupling Coefficient

The coupling coefficient is the term to merge the primary and the secondary windings of the transformer. The value of the coefficient becomes 1, and it can be calculated using (16)

$$C = \sqrt{1 - \frac{L_\mu}{M_\mu}} \qquad (16)$$

$$\Rightarrow \left[1 - \frac{2 s_0^2}{3 L_C (L_t - L_C)} f(\alpha) ln \, \alpha \right]^{\frac{1}{2}}$$
(17)

$$f(\alpha) = \frac{(\alpha - 1)(2\alpha - 1)}{\alpha^2} \qquad (18)$$

4.6. Primary windings

$$L_1 = L_\mu + M_\mu \qquad (19)$$

$$L_2 = \left(\frac{n_2}{n_1} \right)^2 M_\mu \qquad (20)$$

The primary side and the secondary side windings are L_1, and L_2 respectively.

Cross sectional area of the magnetic core

$$A_{effective} \geq \frac{V_{Max} \times \tau_{Ch}}{2 \Delta \beta_{max} n_2} \qquad (21)$$

4.7. Void voltage

$$V_{void} = \dfrac{V_a}{1 + \dfrac{\left(\dfrac{d}{d^1 - 1}\right)}{\varepsilon_r}} \qquad (22)$$

Where the alternating voltage is (V_a), the thickness of the insulating sample is (d), the void is (d^1) and the relative permittivity is (ε_r).
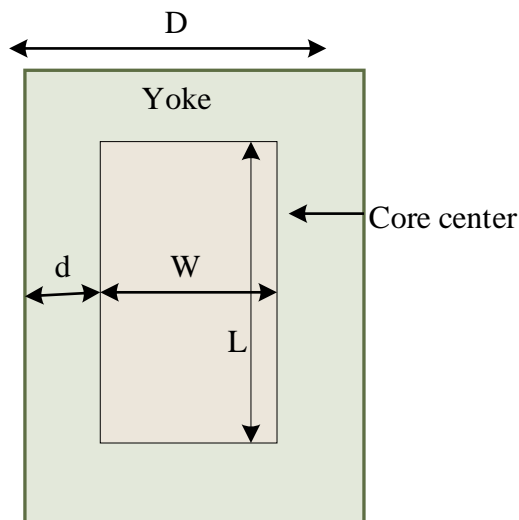

Figure. 2 Dimension of the magnetic frame

5. Proposed methodology

The proposed methodology is characterised as transformer, and the insulation characteristics, which is shown in Figure. 3. The widely used transformer oils are minerals, but it is not much more comfortable. So in this we are going to use the palm oil, because of its better insulation characteristics. The transformer have the primary, and the secondary windings, which are coupled to the coupling ratio which is near to one. So this can be tuned through the elephant herding optimization algorithm. Then the confidence level of the transformer has been improved by the analysis of partial discharge.
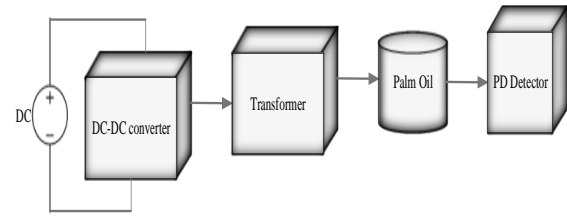

Figure. 3 Block diagram of proposed methodology

The above figure shows that the block diagram of the proposed methodology, in which the transformer is the tesla transformer. The primary and secondary windings are interconnected through the coupling coefficient, which is obtained through the algorithm. The load portion of the transformer is connected with the PD detector. The partial discharge characteristics of the transformer has been obtained at the load side of transformer to validate the efficiency of the proposed system.

5.1. Ultra-wideband magnetic core tesla transformer.

The ultra-wideband magnetic core tesla transformer is compact and portable size, and it have higher pulsation rate. The high voltage pulses are generated through the high voltage generator. The primary and the secondary circuits are carried out in the tesla transformer. In a primary side the windings are in series and the capacitors are connected across the windings. Similar way the secondary windings are connected with the coaxial type capacitor. The schematic structure of tesla transformer is shown in Figure. 4.
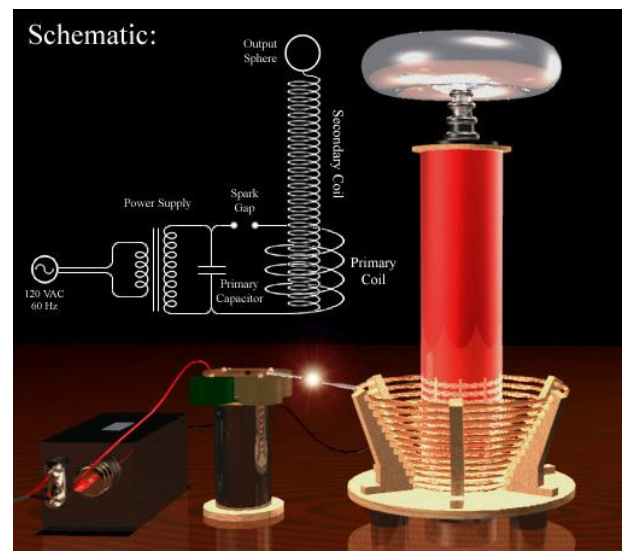

Figure. 4 Schematic of tesla transformer

Fabrication of magnetic core structure using Elephant herding optimization algorithm (EHO).

The coupling coefficient of the magnetic core structure is formulated with the radius and the length of the core, and it is fine under the optimization. The main thinking of the proposed work is to be a maximization of coupling efficient and the values must be close to be one. One kind of largest animal in the world is to be an elephant. It have two recognized species. The major identification of the animal is a long trunk which is for grasping, breathing, and lifting water. Several clans are oriented with the leadership of the matriarch. Under the clan have one female, calves. Among them the female groups are recognized to live together. Even though the male elephants will live away from their family.

The EHO algorithm has three idealized functions which are,

i. The population of elephant is composed into kind of clans. The clans contain the fixed integer of elephants

ii. At each iteration, the male elephants will separated from their family and stay solitary away with their groups

iii. Finally each clans live together with the leadership is named by matriarch.

The algorithm have two operators, which are they,

- Separating operator
- Clan operator

Clan updating operator

In each clan, all the elephants are live together under the leadership. The clan of each elephant is said to be C_i, for the updation of "jth" elephant in the clans by,

$$\chi^{new,C_i,j} = \chi^{C_i,j} + \beta \times \left(\chi^{best,C_i} - \chi^{C_i,j} \right) \times l$$

(22)

The newly updated and the old positions are $\chi^{new,C_i,j}$, $\chi^{C_i,j}$ respectively. The value of β is [0, 1], and it is denoted the term of scalar factor. The fittest function (l) in the EHO is also carried out with [0, 1] and it is refer to (23). The fittest of elephant in the clan are updated by,

$$\chi^{new,C_i,j} = \beta \times \chi^{center,C_i}$$

(23)

The dimension of the clan is to be,

$$\chi^{center,C_i,D} = \frac{1}{N_{Ci}} \times \sum_{J=1}^{N_{Ci}} \chi^{C_i,D,J}$$

Separating operator

The worst fitness is carried out with the separate operator, and it process for each iteration, this has been obtained by,

$$\chi^{Worst,C_i} = \chi_{min} + \left(\chi_{max} - \chi_{min} + 1 \right) \times rand$$

Pseudo code for EHO algorithm

```
Start
Initialize the number of particle
Optimization loop:
Set generation index=1;
    While
Number of valuations<options
Elitism strategy:
     For j=1: keep
End
Clan updation:
    j=1
pop index=1
  pop index= pop index+1
end
    j=j+1
End.
Objective function in (16)
Perform the iteration up to getting the optimal value
end
```

5.2. Partial discharge test (PDT)

The transformer oil is degraded, in which the insulation characteristics of the oil is evaluated through the partial discharge. These are incorporated by collecting the huge data base related to the corresponding oil. Widely used mineral oils have the dielectric strength against the transformer. The mineral oil such as petroleum are formed due to the action of buried vegetables. Recently the vegetable oils are used in the transformer for the corrosive environment. A kind of vegetable oils are natural ester and palm oil, now a days the palm oils are useful in the transformer. The transformer oils have the electrical and the chemical characteristics.

Chemical Characteristics

- Viscosity
- Acidity
- Oxidation stability
- Flash Point

Electrical Characteristics

- Ac breakdown voltage
- Dissipation factor
- Partial discharge

The proposed work have been considered the partial discharge, through this the insulation characteristics of the transformers are identified. If the applied electric fields are exceeds the threshold value then it occurs the partial break down in the transformers when there occurs the PD discharge. In order to keep the transformer from the break down, the needle plane electrodes are carried out with the 20 mm gap distance, and the thickness is about 15mm. This can be mainly focused before breakdown of the medium (solid, and liquid).

5.3. Palm oil

The palm oils are originated from the fruit of palm tree. This tree has been introduced while 15th century, and it had been introduced during the 1870 as an ornamental plant. The palm oil and the palm kernel oils are extracted from the same tree. The palm oil is shown in figure 5.

Figure. 5 Palm Oil

The process flow of the proposed methodology has been shown in Figure.ure 6, in which the steps are proceeded. The tesla transformer design is the important criteria, and the oil testing at the load side is processed.

Table 1. Properties of palm oil

Flash Point(^{0}C)	250
Fire Point(^{0}C)	260
Viscosity(^{0}C)	37
Moisture (%)	0.12
Saturated fatty acid (%)	50
Monounsaturated fatty acid (%)	39.5
Polyunsaturated fatty acid (%)	10.5

The properties of the palm oil at earlier measured data is represented in Table 1.The flash, fire points, viscosity, moisture content is given.
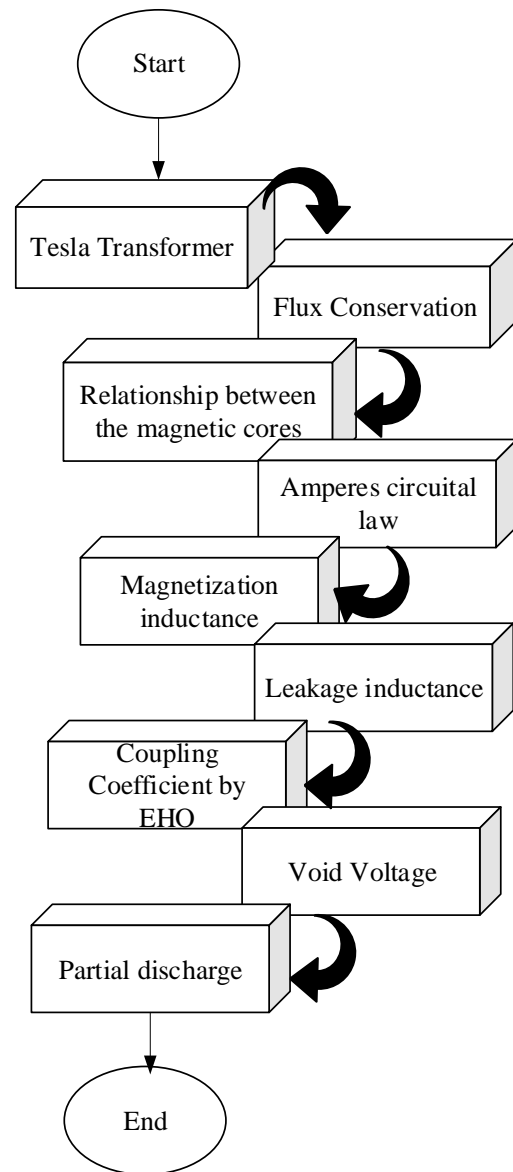

Figure. 6: Flow chart of the proposed methodology

6.   Results and discussion

The tesla transformer has been designed in the proposed works in which the oil testing is carried out for the insulation characteristics.The converter has been designed to obtain the specified voltages, the implementation results are carried out in MATLAB/SIMULINK environment.
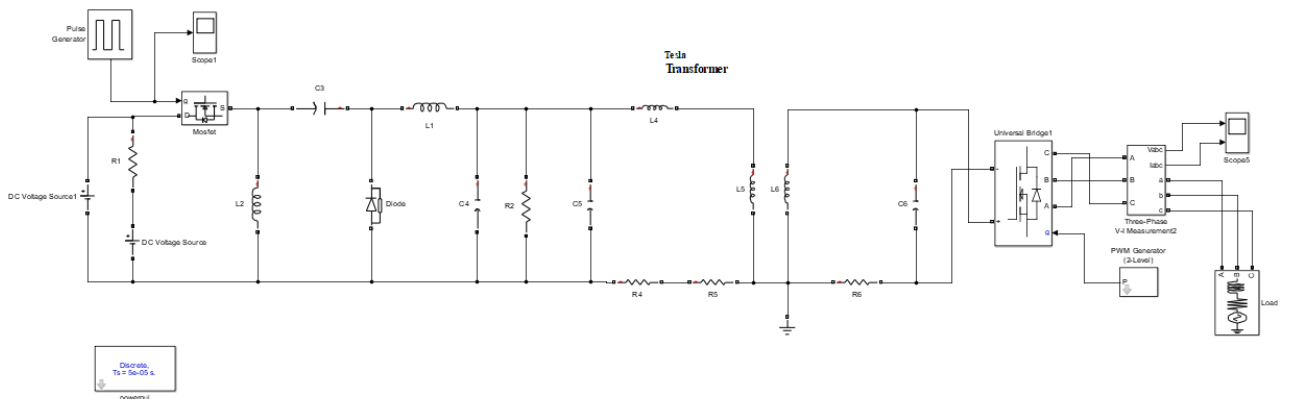
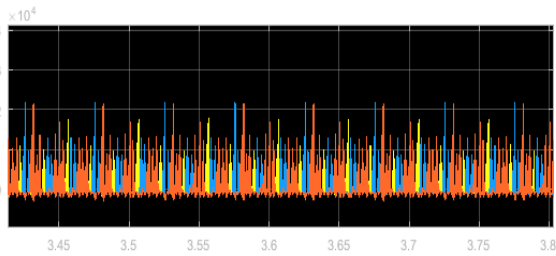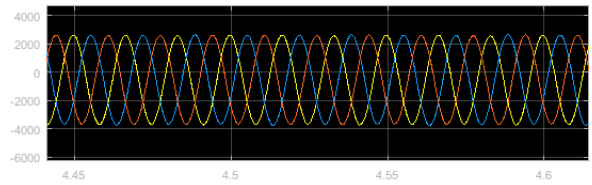**Figure.7 Simulink Model of tesla transformer**

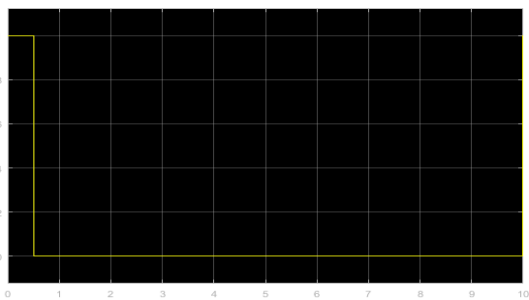**Figure. 8 TransformerVoltage**

Figure. 9 Converter Pulse

Figure. 10 Current

The Simulink model of the transformer is shown in figure 7, voltage, gate pulse, and the currents are given in figure 8, 9, and 10 respectively. The voltage is varied 0 to 2×10^{4}. The pulses are varied.
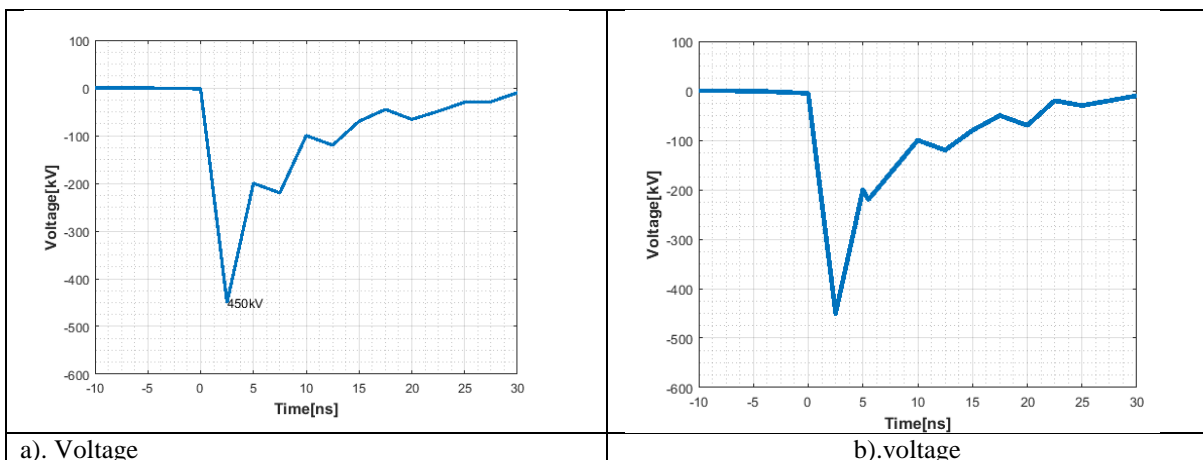

| a). Voltage | b).voltage |

Figure. 11 Voltage obtained from high voltage generator

Table 2. Parameters behind the tesla transformer

DC voltage	800V
L_2	200×10^{-6}
R_1	20Ω
C_1	220×10^{-6}
L_1	220×10^{-6}
C_2	220×10^{-6}
R_2	$20\ \Omega$
C_3	1×10^{-6}
R_3, R_4, R_5	1Ω
$L_3, L_4, L_5,$	1×10^{-3}

7. Conclusion

The tesla transformer have been designed, in which the coupling coefficient is adjusted through the elephant herding optimization algorithm. The parameters values are attached in the table. The rectangle type of the magnetic frame structure is designed. The obtained results from the SIMULINK work is attached in the result section. The palm oil is considered in the load portion of the transformer, which is tested under the partial discharge. This can attain the peak voltage of about 450kv.

References

1. E.Kuffel and W.S. Zaengl, "High Voltage Engineering Fundamentals", Pergamon Press, Oxford, New York, 1984.
2. J. Li, Z. Zhang, P. Zou, S. Grzybowski, and M. Zahn, "Preparation of a Vegetable Oil-based Nanofluid and Investigation of Its Breakdown and Dielectric Properties", IEEE Electr. Insul. Mag., vol. 28, no. 5, pp. 43-50, 2012.
3. Suwarno M. Ilyas, "Study on the Characteristics of Jatropha and Ricinnus Seed Oils as Liquid Insulating Materials", in Proc. of the Annual Report Conference on IEEE Electrical Insulation and Dielectric Phenomena, pp.162-166, 2006.
4. C. P. McShane, K. J. Rapp, J. L. Corkran, G. A. Gauger, and J. Luksich, "Aging of Kraft paper in natural ester dielectric fluid," IEEE International Conference on Dielectric Liquids (ICDL), pp. 173- 177, 2002.
5. D. L. Harris, and P. McShane, "Natural Ester Transformer Fluids: Safety, Reliability & Environmental Performance," IEEE Petroleum and Chemical Industry Technical Conference (PCIC), pp. 1-7, 2007.
6. X. Wang and Z.D. Wang, "Study of dielectric behaviour of ester transformer liquids under ac voltage," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 19, pp. 1916-1925, 2012.
7. Huifei Jin, Thomas Andritsch, Ioannis A. Tsekmes, Roman Kochetov, Peter H.F. Morshuis, Johan J. and Smit, "Properties of Mineral Oil based Silica Nanofluids," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 21, no. 3, pp. 1100-1108, 2014.
8. Dong, M, L. P. Shen, H. Wang, H. B. Wang, and J. Miao, "Investigation on the Electrical Conductivity of Transformer Oil-Based AlN Nanofluids," Journal of Nanomaterials, Hindawi Publishing Corporation, vol. 2013, pp. 1-7, 2013.
9. Ramu, T.S., B.K. Keshavan, and K.N. BalasubramanyaMurthi, "Application of a Class of Nano fluids to improve the Loadability of Power Transformers," IEEE 10th International Conference on the Properties and Applications of Dielectric Materials, 2012.
10. Jian Li, Zhaotao Zhang,Ping Zou and Stanislaw Grzybowski, "Preparation of a Vegetable Oil-Based Nanofluids and Investigation of Its Breakdown and Dielectric Properties," IEEE Electrical Insulation Magazine, vol. 28, no. 5, pp. 43-50, 2012.
11. D. Prasad, and S. Chandrasekar, "Investigations onDielectric Performance Characteristics of NaturalEster based Nano-Fluids for Power TransformerApplications," Asian Journal of Research in SocialSciences and Humanities, vol. 6, no. 11, pp. 1146-1157, 2016.
12. D. Imamovic, K.X. Lai, N.A. Muhamad, B.T. Phung and T.R.Blackburn, "Partial Discharge and Dissolved Gas Analysis in Bio-Degradable Transformer Oil," in Proc. of Cigre, pp. 1-7, 2007.
13. A. A. Abdelmalik, J. C. Fothergill, S. J. Dodd, A. P. Abbott, and R. C. Harris, "Effect of side chains on the dielectric properties of alkyl esters derived from palm kernel oil," International Conference on Dielectric Liquids (ICDL), pp. 1-4, 2011.
14. Suwarno, F. Sitinjak, I. Suhariadi, and L. Imsak,"Study on the characteristics of palm oil and it'sderivatives as liquid insulating materials," International Conference on Properties and Applicationsof Dielectric Materials (ICPADM), vol. 2, pp. 495-498, 2003.
15. N. Azis, "Ageing assessment of insulation paper with consideration of in-service ageing and natural ester application," PhD dissertation, School of Electrical and Electronic Engineering, The University of Manchester, 2012.
16. Shriram RA, Chandrasekar S, Karthik B. PD Signal Time-Frequency Map and PRPD Pattern Analysis of Nano SiO_2 Modified Palm Oil for Transformer Insulation Applications.

Journal of Electrical Engineering & Technology. Vol.13, no. 2, pp. 902-910, 2018.

17. Azis N, Jasni J, AbKadir MZ, and Mohtar MN,"Suitability of palm based oil as dielectric insulating fluid in transformers," Journal of Electrical Engineering & Technology, vol. 9, no. 2, pp.662-669, 2014.

18. Senthilkumar S, Karthik B, and Chandrasekar S, "Investigations on PD characteristics of thermal aged palm and corn oil for power transformer insulation applications," Journal of Electrical Engineering & Technology, vol. 9, no. 5, pp. 1660-1669, 2014.