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Fault Identification of 45MVA Transformer Winding by Changing Capacitance Value Using Frequency Response Analysis with Artificial Bee Colony Method

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Abstract: **This paper shows the result of employing frequency response analysis for synthesizing 45MVA transformer winding parameter which has been optimized by artificial bee colony (ABC) method. The applied optimization method is suitably adopted by effective parameters, defined values and bounds to the research area and thereby ensures the good performance of transformer by frequency response analysis. The selected frequency range FRA data gives a report on bode diagram. Objective of this research work is to minimize the resonance frequency of transformer by changing the capacitance value of transformer winding and analyzing the different condition of winding e.g. healthy winding and faulty winding condition which include severe winding condition also. Reference input impedance frequency response has been calculated by an electrical circuit model of three phase transformer healthy condition. That FRA response has been used for comparison with faulty condition response of transformer winding. This method has advantages in terms of fault analysis in transformer winding, less parameter and time efficient method. Stability of our system can also be examined by clear shift of resonance point in characteristic of FRA.**

Keywords: **power transformer, Frequency Response Analysis, Artificial bee colony method Fault analysis, Winding deformation.**

1. INTRODUCTION

Power transformer is a heart of power system used as main equipment in transmission and distribution of electrical power. Here we study about 45MVA power transformer diagnosis approach [1]. Any type of fault in transformer damage the whole system and connected machines also. To prevent this, analysis of transformer plays an important role. We introduced an analytical approach called frequency response analysis which utilize by Dick and Erven. FRA is considered as a advanced technique for transformer winding investigation [2]-[5]. We can take the value of resistance capacitance and inductance of 45MVA transformer winding in frequency measurement as reference data [8]-[9]. Change in the shape of transformer winding changes will lead to frequency response trace deviation and fault recognition accordingly [10]-[12]. The characteristic of FRA data shows the clear shift of resonance point may characterize faulty condition.

Transformer insulation is subjected to many stresses during the operation due to which winding of transformer affected [11]-[12]. Due to this transformer winding analysis is important. During the last two decades, Artificial Intelligence (AI) techniques such as Evolutionary Programming (EP) Genetic Algorithms (GA), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) have been developed to optimize FRA analysis problems. This paper presents the implementation of Artificial Bees Colony (ABC) algorithm for optimization FRA analysis problem [6]-[9]. Transformer winding deformation creates faulty condition of transformer. Here we analyze that fault with impedance measurement of winding with the help of FRA [13]-[15]. In the electrical circuit of transformer winding resonance frequency is examined by changing the value of capacitance. That variation of capacitance at the particular band of frequency range gives output for analysis.

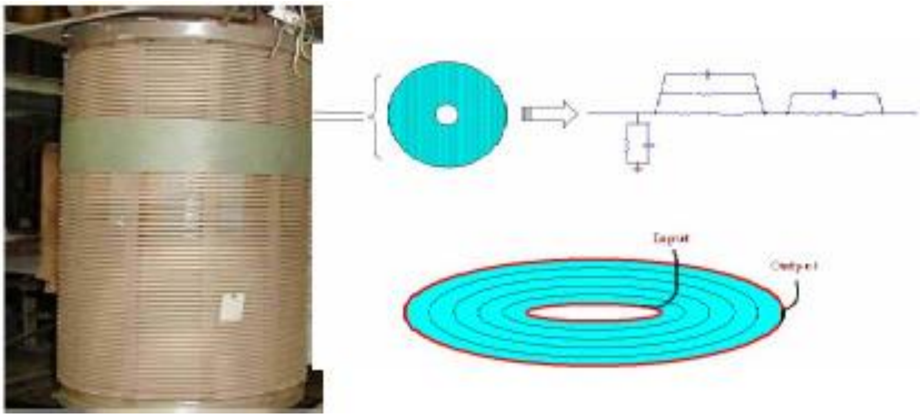

Fig.1. Continuous parameter modal of transformer winding

2. LUMPED ELECTRICAL NETWORK OF TRANSFORMER WINDING

In Fig. 2, N section, ladder network corresponding to an isolated transformer winding is shown. Each section of transformer winding made identical to each other for analyzing purpose. Typically, such a network is made up of impedance (Z), series capacitance (C_s), ground capacitance (C_g) and inductance (L). It is true that frequency of the system affected by capacitance and inductance of transformer winding in terms of resonance. We use capacitance as a main affected parameter of transformer winding in this research work. Inductance and resistance are the constant and neglected parameters respectively because resistance of winding not affected resonance of circuit. We are taking impedance as equivalent of the whole circuit.

2.1 Series capacitance (C_s): Shunt capacitors either at customer location for power factor correction or on the distribution system for voltage controls dramatically alter the system impedance variation with frequency. Capacitors do not create harmonic, but severe harmonic distortion. When the capacitive reactance *XC* of transformer winding decreases proportionately to frequency.

2.2 ground capacitance (C_g): Ground capacitance is also a winding parameter in the network. Any variation of that parameter creates faulty condition in the winding. Capacitance between the ground and winding layer generates harmonic in the network.

2.3 Inductance (L): Inductance between the winding can directly calculated by reference data or it can be measured from the terminals. In this paper L is determined from measurements and given as an input to the program.

3. EQUIVALENT ELECTRICAL CIRCUIT

Simplified equivalent circuit for one phase of winding of the 45MVA, 132/11KV transformer using cascade section modeled for 11 section equal to the number of winding disc in the transformer refer fig (2). The equivalent circuit is useful for winding and is sensitive to winding change. Conversely, a change in response could be related to a calculated amount of winding deformation. The circuit contains i^{th} number of winding for calculation of transformer parameter like ground capacitance, inductance and shunt capacitance with equivalent of inductance. It is represented by an impedance Z in equivalent electrical circuit with capacitance between the adjacent turn within the layer, capacitance to ground and to other windings. Similarly exist to a self inductance for individual turn with layer of winding. High voltage insulation thickness between the secondary winding layers gives rise to capacitance in the same manner, significant capacitance occurs between layers of winding. There are also winding to ground capacitance and winding to winding capacitance to

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primary winding in the network. All the capacitive values contribute to the frequency response around the switching frequency of the winding.

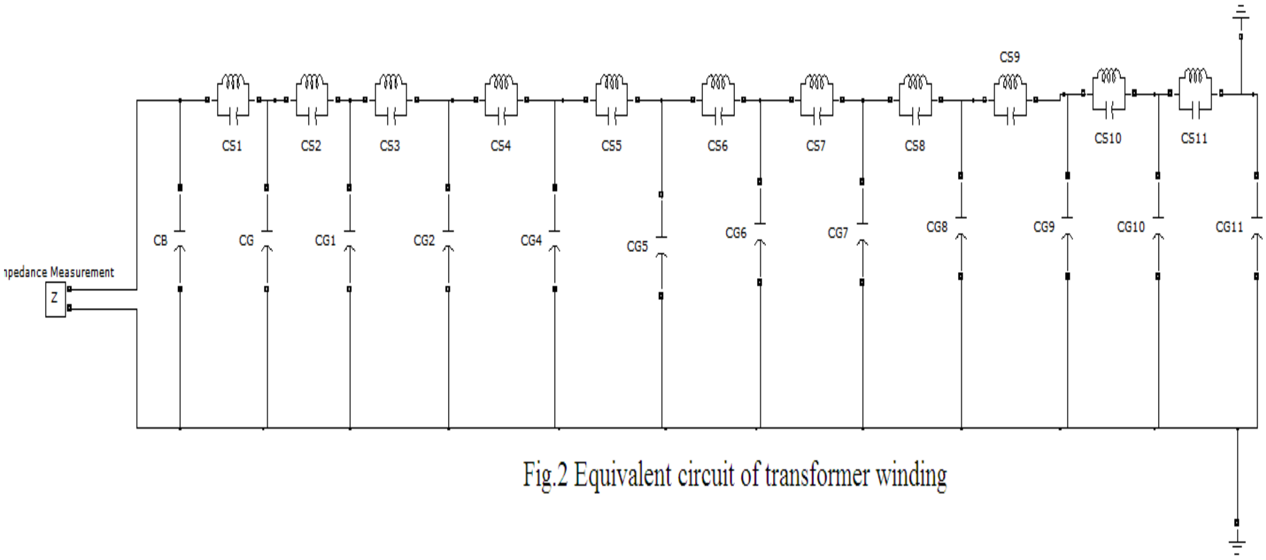

Fig.2 Equivalent circuit of transformer winding

4. FORMULATION OF OBJECTIVE FUNCTION

In FRA data reports as a spectrum in bode plot over a defined range of frequency for transformer winding [5]. Transformer winding deformation depends on the frequency, capacitance inductance and impedance. Here we minimize resonance frequency of transformer winding with capacitance variation of winding, for this lumped electrical circuit constructed and monitored by FRA analysis. After the analysis of bode plot we can explain the stability of our system. The problem can be stated mathematical as:

Objective function

$$Minimize \sum_{i=1}^{n} \mathrm{F}_{\mathrm{i}}(P_i) \qquad (1)$$

Where $F_i(P_i)$= frequency of i^{th} winding of transformer and $F_i(P_i)= 1/2\pi ZC$ through this we can calculate the value of frequency and it should be satisfied as shown in following condition in the define band for minimizing the resonance frequency of transformer winding.

Condition

$F_i(P_i) \leq C(P_i)$ and (2)

$F_i\ (P_i) \leq Z(P_i)$ (3)

Where $C(P_i)^{min}$ and $C(P_i\ )^{max}$ are the minimum and maximum value of capacitance of i^{th} winding respectively, and $F(P_i)^{min}$ and $F(P_i)^{max}$ are minimum

$Z(P_i)$ is the value of impedance of i^{th} transformer winding for circuit of transformer winding Inequality equation are :

$C(P_i)^{min} \leq C(P_i) \leq C(P_i)^{max}$ (4)

$F(P_i)^{min} \leq F(P_i) \leq F(P_i)^{max}$ (5)

Where $C(P_i)^{min}$ and $C(P_i\ )^{max}$ are the minimum and maximum value of capacitance of i^{th} winding respectively, and $F(P_i)^{min}$ and $F(P_i)^{max}$ are minimum and maximum value of frequency of i^{th} winding respectively.

5. ARTIFICIAL BEES COLONY ALGORITHM

The problem is a constraint multi-objective optimization problem and is solved with artificial bee colony i.e. ABC method [6]-[8]. The ABC algorithm is a swarm based meta-heuristic algorithm which was introduced by Karaboga in 2005 for optimizing high dimensional numerical problems. It was inspired by the intelligent foraging behavior of honey bees. In ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. First half of the colony consists of the employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources. The employed bee of an abandoned food source becomes a scout. ABC is also an iterative process like other population based algorithms. The search carried out by the artificial bees

can be summarized by a number of actions as initialization of the population, initialization of the bee phase, calculating probability values involved in probabilistic selection, onlooker bee phase, scout bee phase. The solution of the present optimization problem with the ABC method has been described by the following steps.

Step I: The ABC generates a randomly distributed initial population of NP solutions using the following equation

$$\varphi ij = lj + rand\ (0,1) \times (u\ j - l\ j\ ) \qquad (1)$$

where i = {1, 2, . . . , NP} and j = {1, 2, . . . ,D}, l_j and u_j are the lower and upper bound of the solution variable , NP is the size of population, and D is the number of optimization variables .

Step II: After initialization, the population of the solutions is subjected to repeated cycles, C = 1, 2. . . MCN (maximum cycle number) of the search process of the employed bees, the onlooker bees and scout bees. An artificial employed or onlooker bee probabilistically produces a modification of the solution in her memory for finding a new food source and evaluates the nectar amount (fitness value) of the new source (new solution).

Step III: After all employed bees complete the search process; they share the nectar information of the food sources (solutions) and their position information with the onlooker bees on the dance area. An onlooker bee evaluates the nectar information acquired from all employed bees and chooses a food source with a probability related to its nectar amount. This probabilistic selection depends on the fitness values of the solutions in the population. In basic ABC, roulette wheel selection scheme in which each slice is proportional in size to the fitness value is employed as follows

$$P_i = fit_i \Big/ \sum_{i=1}^{NP} fit_i \qquad (2)$$

Where fit is the fitness value of the solution i evaluated by its employed bee. This is proportional to the nectar amount of the food source (J_i or fit_i) in the position i. In this way, the employed bees exchange their information with the onlookers.

Step IV: In order to produce a new candidate food position from the old one, a greedy selection mechanism is employed between the old and candidate solutions using the following expression

$$v_{ij} = y_{ij} + k_{ij}(y_{ij} - y_{kj}) \qquad (3)$$

where k = {1, 2, . . . , BN}; BN=number of employed bees and j = {1, 2, . . . ,D} are randomly chosen indexes. Although k is determined randomly, it has to be different from i. k_{ij} is a random number between that [-1, 1]. It controls the production of a neighbor food source position around y_{ij} and the modification represents the comparison of the neighbor food positions visually by the bee. Equation (3) shows that as the difference between the parameters of the y_{ij} and y_{kj} decreases, the perturbation on the position y_{ij} decreases, too.

Step V: The food source whose nectar is abandoned is replaced by the scouts. In the ABC algorithm, if a position cannot be improved further through a predetermined number of cycles, called limit, then that food source is assumed to be abandoned.

Step VI: After each candidate source position v_{ij} is produced and then evaluated by the artificial bee, its performance is compared with that of y_{ij}. If the new food has equal or better nectar than the old source, it is replaced with the old one in the memory. Otherwise, the old one is retained. This process is repeated by a number of cycles (MCN). The best result obtained during this process is accepted as the optimum result.

In this paper, the Bees Algorithm was applied mainly for calculating the optimum solution of each value of capacitance of transformer winding and optimizes the impedance of winding. Initially, a number of scout bees were determined to search between maximum and minimum limits of the frequency value, after that the objective function according to equation was evaluated and verified its convergence towards the optimal solution. The Bees Algorithm, then, updated its parameters to better values and these steps were repeated until reaching the optimal solution or the stopping criterion was met. Flow chart of ABC algorithm clears the whole steps of optimization. ABC algorithm is a effective and time efficient method.

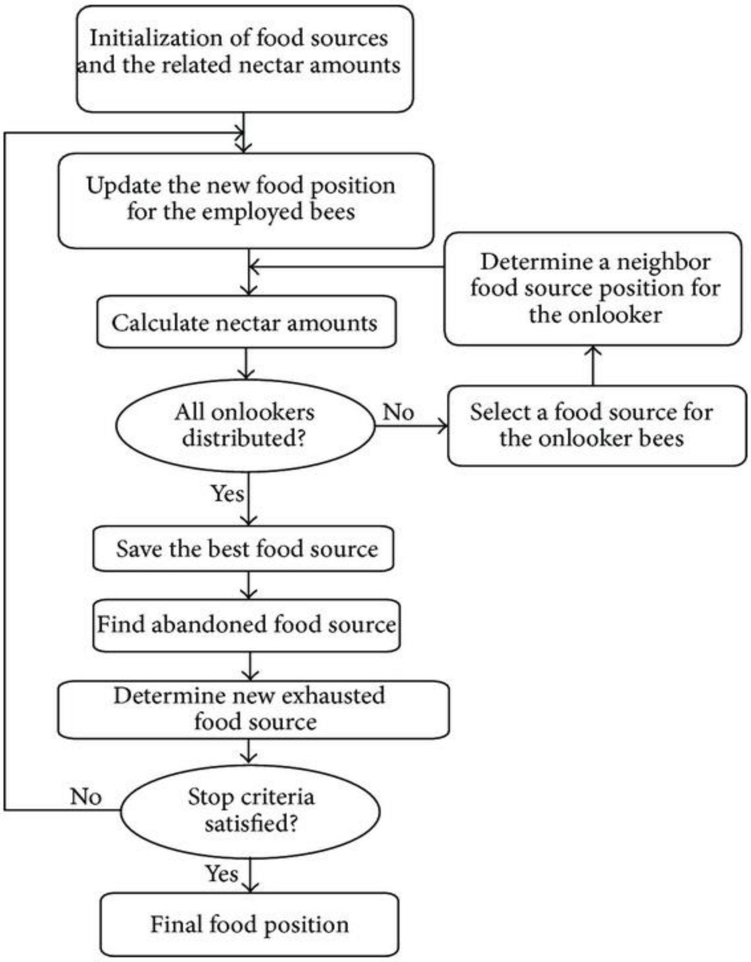

Fig.3 Flow chart of ABC algorithm

6. SIMULATION RESULTS AND COMPARISION

In order to analyze the identification accuracy of the proposed approach, the lumped parameter model, of a 3-phase experimental transformer (45 MVA, 132/11 kV) having a Δ-Y winding configuration is employed to calculate reference input impedance frequency responses to its high degree of simulation accuracy in comparison with simulation of transformer winding.. The comparison of the responses in the fig (4) show a good resemblance both in resonance frequencies and magnitudes between the responses at low frequencies associated with the transformer core. We can see that in gig (5) and fig (6) show winding faulty condition due to deformation of transformer winding using FRA measurements.

Electrical network fig (2) simulated on different condition for analysis of winding with the bode spectrum of FRA. That analysis compare by a healthy circuit with the help of simulation. Transformer winding conditions are demonstrated with the help of output response of FRA analysis. Result of series and shunt capacitances, capacitive reactance in the case of high-frequency band could be neglected as its reactance is reaching to enough low values. Any changes in the value of capacitances as well winding length may lead to changes in resonance frequencies.

A transformer of 45 MVA was chosen for the fig (2) test system and the simulation results obtained from the Bees Algorithm after performing 2500 runs were compared. From the results, it can be clearly seen that the value of impendence obtained from ABC was more effective then the result of FRA. Moreover, the computational time of ABC was less than the other remaining methods. The Bees Algorithm was able to determine a possible solution close to the optimum point. Applying the Artificial Bees Algorithm to solve and optimize FRA analysis of transformer winding was carried out on electrical circuit. Network of fig (2) is an electrical network of transformer winding which contain series capacitance and parallel connection of inductance and capacitance. They were implemented in MATLAB and run on the AMD AthlonTM 1.5 GHz processor with 4.0 GB of RAM.C20 is the name of testing transformer winding network. That network use for analysis purpose in the simulation. Lumped parameter of the network is capacitance of transformer winding.

Table 1: Comparison of different winding condition

Winding Condition	Analysis	Deviation In response	Output graph
Close circuit	Healthy condition	0%	Overlap each other
Change the value of parameter	Faulty condition	10%	Slightly change the position of graph
Open circuit	Severe condition	100%	Not overlap each other

Table 2: analysis of FRA data by changing the value of capacitance parameter

Condition	Capacitance (F)	Magnitude (DB)	Resonance frequency (Hz)
Healthy condition	7.909×10^{-12}	10^{6}	170
10% increase in Cs	8.700×10^{-12}	2×10^{6}	169
10% in Cs decrease	7.118×10^{-12}	3×10^{6}	167

6.1 Comparison of output graph:

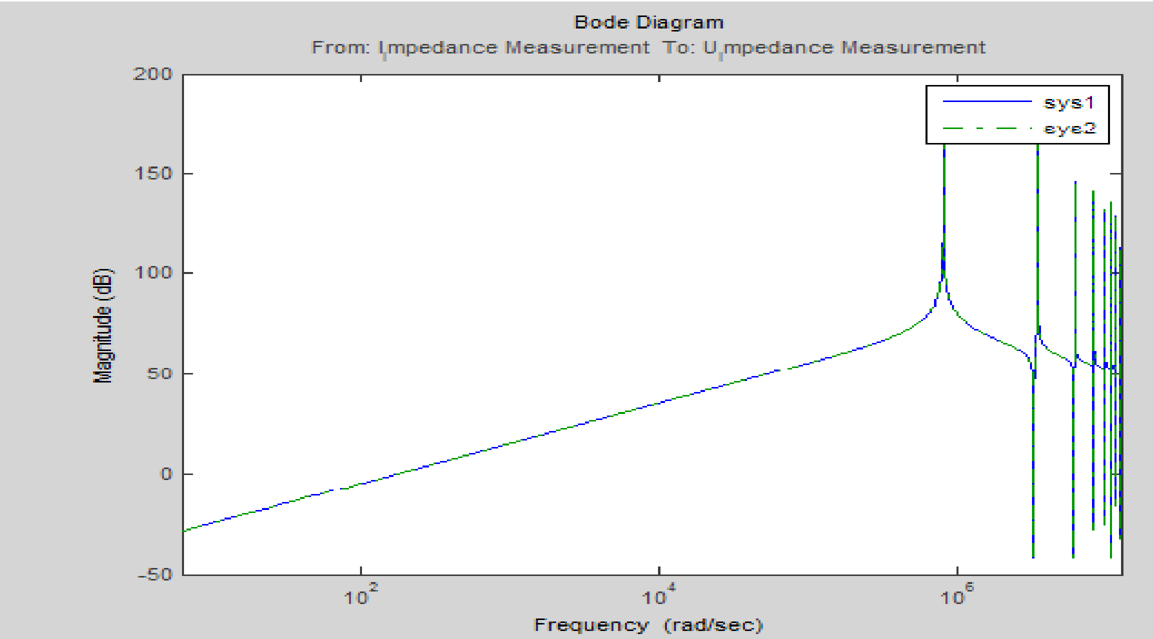

Fig.4. comparison of the input impedance magnitude frequency response of a there phase winding reference transformer model and testing model when fault occurs.

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The response of fig 4 shows the healthy condition of tested transformer winding with reference of healthy system. From the diagram we can say that the first resonance peak is appearing at frequency response plot with maximum amplitude. We can see that after first resonance, damping increase with number of cycle per second. Overlapping of the frequency response spectrum of both reference and testing system shows that there is no fault in the winding of testing transformer. Our system can run efficiently as reference system.

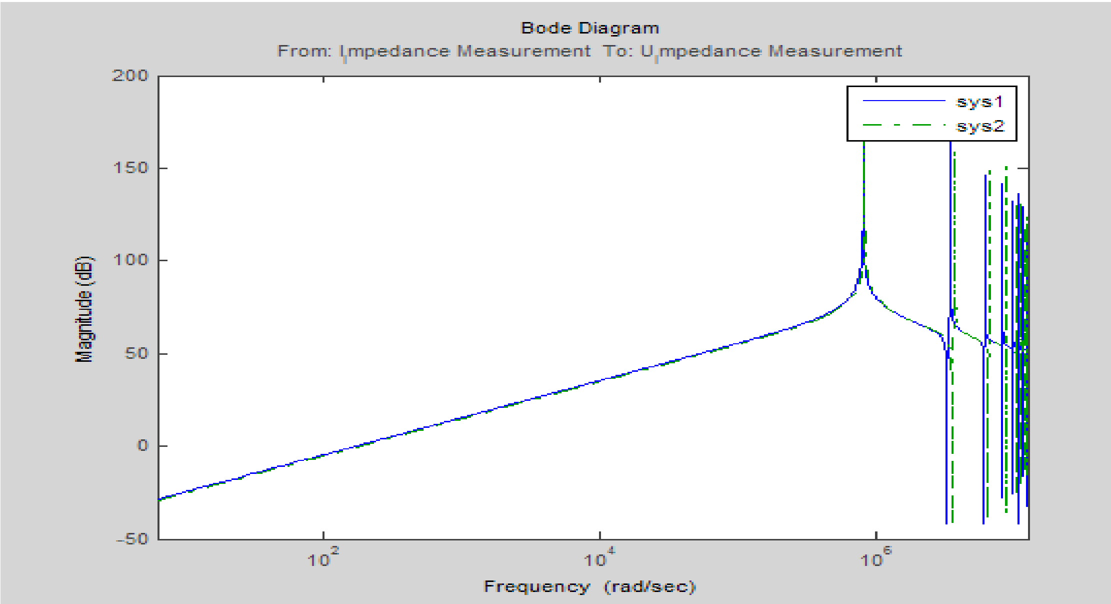

Fig.5. comparison of the input impedance magnitude frequency response of a there phase winding reference transformer model and testing model when fault occurs.

Frequency response analysis basically use for fault analysis in transformer winding by showing the deviation in the spectrum of analysis. Here we can see that in the fig (5) fault occur in the transformer winding by changing the graph position of testing system with comparison of reference system. Resonance peak of testing system slightly decrease with increasing the value of capacitance parameter of transformer circuit model. This shows the deformation in the transformer winding.

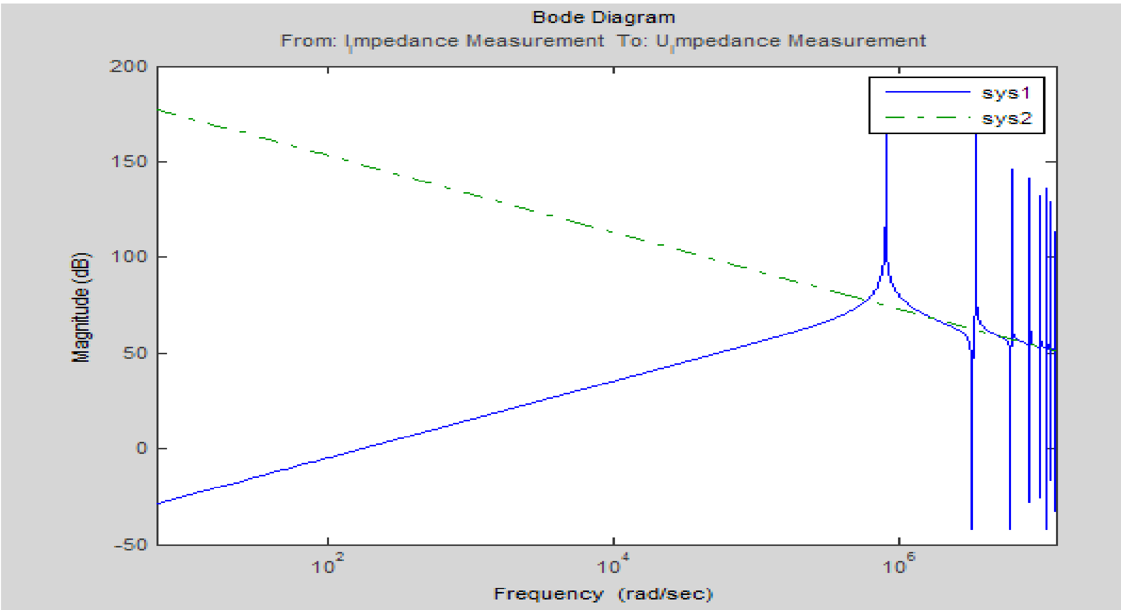

Fig.6. comparison of the input impedance magnitude frequency response of a there phase winding reference transformer model and testing model when winding open circuited

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Response as shown in fig (6) indicates that the most dangerous condition of transformer winding. After the fault occurrence plot of testing system appear differently as reference system plot. Severe condition occurs due to open the winding connection by change its capacitance value. Testing system frequency plot decrease its value with undefined range of frequency and magnitude.

Comparison of responses of those three figures shows a good resemblance both in resonance frequency and magnitudes between the responses at mid frequencies associated with the transformer core winding. ABC algorithm has been used to optimize the transformer parameter of transformer winding core parameter. As a result, an accurate model of transformer winding is developed, which can applied to FRA result interpretation at mid frequencies. Mid frequency region associated with winding structure [1]. Fig (7) shows the healthy and faulty condition of transformer winding.

Fig 7 winding at faulty condition

7. CONCLUSION

Every transformer has some signature that is sensitive to change in transformer parameter of winding like capacitance, résistance, inductance and frequency. For any change in winding geometry, FRA is power full tool for an analysis of deform condition of winding by its spectrum. The research work was conducted based on the analysis diagnosed by FRA on the 45MVA transformer winding by changing the capacitance value of winding parameter. Result of FRA successfully demonstrates different condition of transformer winding. It is certainly time efficient method and was found to further use for other value of transformer parameter for fault detection. Type of fault can also be determined in further research work. Further work can be done to enhance the present optimization method (ABC).

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