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Frequencies Dominations for Different Rating of Distribution Transformer under Transients

Haseeb Faisal[1], Dr. Kashif Imdad[2], Najeeb Hussain[3], Faisal Sharif[4],
[1,2,3]Department of Electrical Engineering, HITEC University Taxila, Punjab, Pakistan
[4]WAPDA, Islamabad, Pakistan.
haseebf1@hitecuni.edu.pk[1], engr.kashif@hitecuni.edu.pk[2], najeebhussain@hitecuni.edu.pk[3]
faisalsharifch@gmail.com[4]

Abstract—Power transients faults on high voltage lines are prominently due to high frequency transients. These transients affect the predicted life and efficiency of equipment. The Fast Fourier Transform (FFT) is helpful in analysing the effect of high frequencies and Frequency Response Analysis (FRA) provide support in diagnosis and detection of deformation in a transformers. The major aim of this study is to analyse the incorporation of frequencies based on resonating core of a particular transformer. Using transfer function method an impedance change in transformer has been observed when equipment is subjected to high voltage transients. The effect of change in impedance is that it degrade the life of a core with respect to time. In this paper, research that has been done already on Transformers of different ratings i.e. 100, 50 and 30 kVA are studied and then an experiment is performed on 50-kVA transformer. It was concluded that the core of a transformer having rating equal or less than 50 kVA practically shows single resonance behavior while above 50 kVA for instance 100-kVA transformer core resonates twice. In actual, result defines the core deviating frequency with respect to the rating of a transformer.

Keywords— Frequency dominations, transients, Fast Fourier Transform, distribution transformer, high frequency modelling.

I. INTRODUCTION

A transformer is one of the expensive component in the power industry. Due to transients the efficiency of a transformer decreased and not effectively perform its function on the distribution side of a power system. In order to provide protection to the equipment; power transient measurement and analysis through high frequency modeling and study of frequency dominations is important. In literature, it was came into consideration that transformer winding has been the integral point of focus with respect to different faults for example, transformer winding deformation. Transformer winding deformation mainly occurred when transformer relocated from manufacturing plant to the operational area as in [1] [5]. Diagnoses on the bases of inter-turn faults need modeling of transformer winding. The modeling of transformer winding depend on its construction and study of the electrical stresses. In transformer diagnosis, reverse engineering method was adopted in general using black box analysis and its input and output (voltages, currents) were measured. Transformer models were developed to estimate transferred surges from High Voltage (HV) and Low Voltage (LV) line. These Models were valid for unloaded conditions [6] [8]. However, there are models that were functional for both loaded and unloaded conditions as described by [9] [10], they introduced an efficient model under electromagnetic transients. To calculate the transferred surges, distributed and lumped parameters models were used as in the paper [11] [19]. With the bandwidth up to 1MHz lumped parameters analysis were used; comparatively for satisfactory results, distributed parameter models were preferred. Problem is that, [8] defined dual resonance, while [7] presented single resonance behavior. However, no one clearly elaborated the dual and single core resonating frequencies exactly with respect to the rating of the transformer. Reference [20] described the sweep frequency analysis, to assess the mechanical deformation of a transformer core and found that the frequencies less than kHz are much more effective in enhancing mechanical efficiency of a transformer.

In this paper, a concept has been develop to examine the effect of high frequencies on the core in the form of resonance under the influence of high transient fault. The idea is based on the modeling of the equivalent circuit at low frequencies. In open circuit test of a transformer at low frequencies, core resistance and reactance are calculated. The output of an experiment was observe at open circuit noting that under the impulse voltage injection on primary and secondary side the core voltage is resonating and its characteristics are changing.

An experiment is performed on a distribution transformer aiming to define dominating frequencies for transformers of

different kVA rating. This research is two dimension in nature. In first dimension, an experimental approach is developed and secondly based on the past-published researches a comparison has been made with addition of experimental results that validates domination of the frequencies. This concept is competitive in term of defining single or dual resonance with respect to transformer ratings.

II. RESEARCH METHODOLOGY

A. Experimental Setup

The initial setup as shown in Fig.1 is comprised of a distribution transformer of 50 kVA (11 kV/440V), 3-phase; delta-star connection was designed in Universitat Politècnica de Catalunaya Barcelona, Spain.
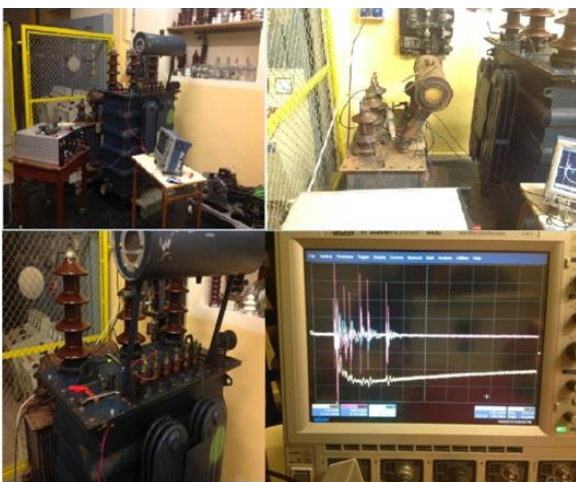

Fig. 1. Experimental Setup for 50kVA transformer.

To determine input and output values, 3-channel oscilloscope is used having a sampling time of 2×10^{-9}. The experimental configuration of the transformer is based on the model presented as in Fig. 2. All phases of the primary side of a transformer are kept short circuit so that each phase have same behavior as other. Corresponding phase input voltage and currents are measured to see the impedance change in core. In actual the mutual induction phenomenon in all phases affects the core but here it is assumed that all phase has similar windings in magnetizing the core. Secondary is open to analyze the behavior of a core under open circuit test. Finally, different values for transfer function method: I of primary and V of secondary under the influence of impulse voltage injection at primary are found out.

At the high voltage (primary) and on the low voltage side (secondary) side of the transformer, a surge voltage is applied. Output voltage is measured by the help of configuration as shown in Fig. 2. On different magnitude of surge voltages at the HV side, different current injections and output voltages are observed. Channel 1 (CH1) is used for the measurement of V_1, Channel 2 (CH2) is used for the measurement of I_1 and channel 3 (CH3) is used for the V_2. Secondary current is not measured

because secondary is open so I_2 is equal to zero. The injected voltages and currents are shown in the Fig. 3. And Fig. 4.
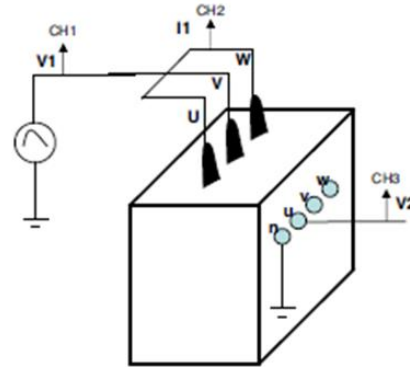

Fig. 2. Experimental configuration of 50kVA transformer.

B. Transfer Function Method

Impulse test has been performed by using two-port network theory. Secondly, transfer function is applied in term of
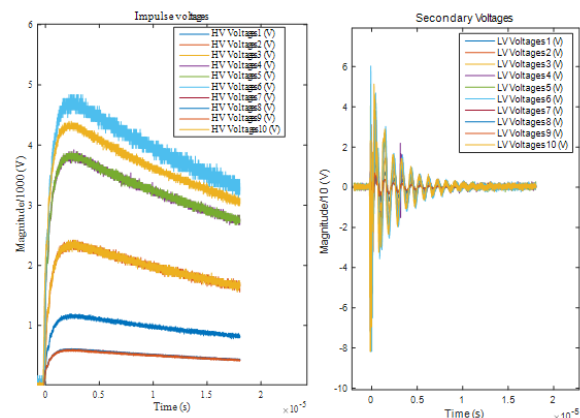

Fig. 3. Different impulse voltages at HV and secondary voltages at LV side.
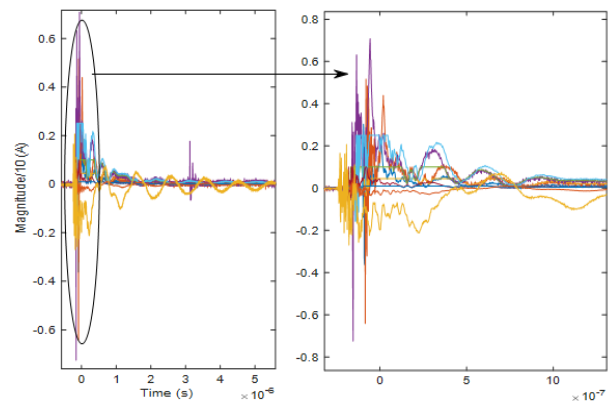

Fig. 4. Different injected currents on primary side.

impedance to see the core impedance behavior.

The purpose of using transfer function method is to identify how much input (impulse voltage) is transferred towards output

and under these constraints what will be the behavior of the core. This transfer function *TF* as in (9) describes the effective transformation of output voltage in term of input current that is known as transformed impedance. The equations for the two-port network theory are:

$$V_p = Z_{11} \times I_P + Z_{12} \times I_S \tag{1}$$
$$V_S = Z_{21} \times I_P + Z_{22} \times I_S \tag{2}$$

$$Z_{12} = \frac{V_P}{I_S} \qquad \therefore I_P = 0 \tag{3}$$
$$Z_{21} = \frac{V_S}{I_P} \qquad \therefore I_S = 0 \tag{4}$$
$$Z_{11} = \frac{V_P}{I_P} \qquad \therefore I_S = 0 \tag{5}$$
$$Z_{12} = \frac{V_S}{I_S} \qquad \therefore I_S = 0 \tag{6}$$

For the analysis of the digital tested data under open circuit test, frequency domain analysis are performed under the transfer function method by using Fast Fourier transform as followed by the equation:

$$X(k) = \sum_{i=1}^{n} x(j)\omega_n^{(j-1)(k-1)} \tag{7}$$

Where,

$$\omega_n = e^{\frac{-2\pi i}{N}} \tag{8}$$
$$TF = \frac{V_{out}}{I_{in}} = \frac{V_{secondary}}{I_{primary}} \tag{9}$$

Here, T_{sample} is the sampling time, which is dependent on the selection of the samples matched closely to each other; in actual it is dependent on the required resolution, so that the outcome should be good.

$$T_{sample} = \frac{L}{N} \tag{10}$$

Where L is the length of a signal and N representing the number of samples.

C. Frequency Analysis & Discussion

The reason of this analysis is to observe that how many times core will resonate, when fault occurs at the HV side of the 50 kVA or less than 50 kVA transformer. Another issue is to see the dominating resonance frequencies because the resonating frequencies having low weight will not affect the core and hence their effect cannot incorporate as far the concern of developing a protection scheme model.

The obtained discrete data is imported to MATLAB, then Fast Fourier Transform algorithm is applied to recognize the behavior of core in term of core resonance. Analysis was done on frequency bandwidth of 100 kHz and 1 MHz as in [7] [8].

On single resonating response of transformer core, there are three zones. In zone one, on primary side of a transformer the highest current injection at which core resonates is at frequency
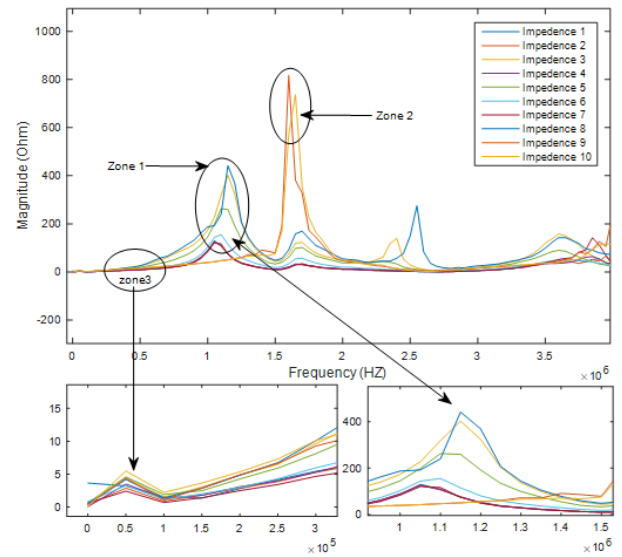

Fig. 5. Frequency vs magnitude response of transfer impedance.

of 1.05×10^6 having Z equal to 130 Ω As in Fig. 5.

Decreasing the value of injecting current an impedance increases and due to this frequencies are increasing; frequency is 1.15×10^6 having Z is 441.9 Ω.

In the zone 2, when we decrease the current at HV side then frequency response move towards dominating resonance frequency and impedance are also increased; *f* is 1.65×10^6 while Z equal to 736.7Ω.

In zone 3, there is resonating frequency for every value of injected current but the frequency involvement in term of its weight is too low that it has no effect on the core. At frequency *f* equal to 1.277×10^5 transformer core resonate and its response changed from capacitive to inductive behavior. It is very clear from above figure that domination of high frequency is only for the core resonance. The relation between impedance and current is inverse in nature so current is decreasing while impedance is increasing and high frequency is moving ahead.

From frequency response, it has been observed that there is only single core resonating frequency, which is dominating over all other frequencies and affects the core in terms of deviating the response and resonating the core.

For different transfer impedances, three edges are considered for analysis of core resonance in between frequency vs phase angle response as in Fig. 6. Edge one, show that response of core is shifting from inductive to capacitive; which is for the low resonating frequencies. Magnitude response is describing, that resonance is negligible when resonating frequencies have low weights in term of magnitude.
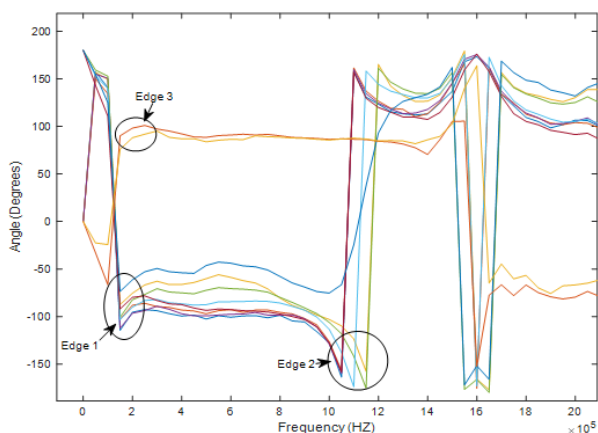
Fig. 6. Frequency vs phase angle response of transfer impedance.

Edge 2 is representing the response for frequency greater than 1 MHz dominating frequencies. The response of these dominating frequencies is changing from capacitive to inductive. This resonance is responsible in increasing the aging of transformer in term of core.

Edge 3 is describe the values or limit of current injection at High Voltage (HV). On this point current is very low, surge voltages and impedances are high. Dominating resonance is also high with respect to previous ones.

So, from the phase angle response it is very clear that in all entire defined bandwidth there is just single dominating resonance frequency for 50-kVA transformer.

D. Concept justification by literature investigation

In this part of the research, we are actually interested in elaborating and justifying our concept. The investigated research was presented in Finland and in Brazil at 100 kVA, 50 kVA and 30 kVA rating transformers.

Fig. 7. Represents the transfer impedance magnitude and phase angle of 100 kVA transformer. In the characteristic impedance figure dual resonance occurring. F_1 which is 374 kHz approximate, occurred at low frequency having a weight of 550Ω approx. and it resonate the core from inductive to capacitive, due to this heavy weight of low frequency was kept in consideration for modelling purposes. While F_2 was 1.36 MHz approximate, occurring at high frequency having an equivalent weight and it is resonating the core from capacitive to inductive. At F_2 the core was at high frequencies but it was responsible to switch the response in actual way normally inductive and at very high frequencies response become capacitive. Fig. 8. displaying a characteristics transfer impedance of 50 kVA transformer.

In Fig 8. Two frequencies were occurring which resonate the core consequently at F_1 and F_2. F_1 is low resonating frequency, its weight is 40Ω approximate and it resonate the core from inductive to capacitive but the response is much fluctuating and inductive response is dominating over capacitive. F_2 was the
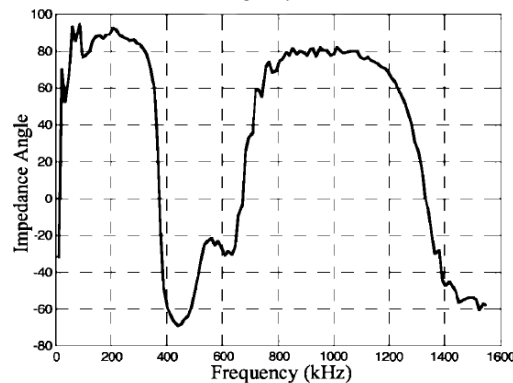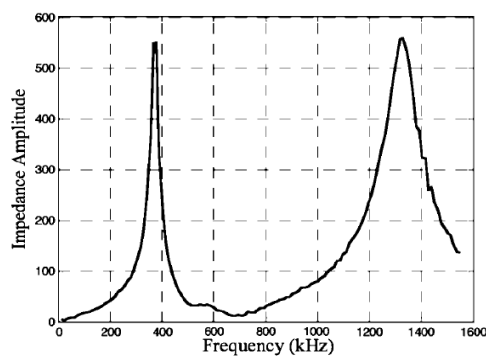

Fig. 7. 100-kVA transformer transfer impedance (reprinted form [8])

highest dominating frequency having weight was 500Ω approx. and response was resonating from inductive to capacitive. The below mentioned result and previous results in Fig. 4. And Fig. 5. Have relevancy, the reason is that both transformer have same ratings.
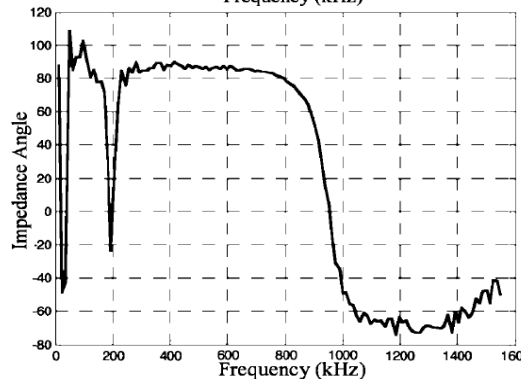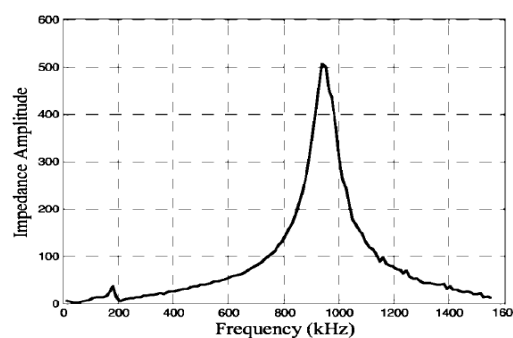

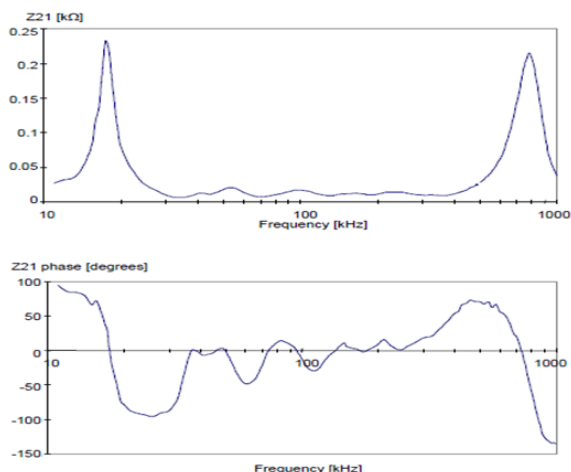Fig. 8. 50-kVA transformer transfer impedance (reprinted from [8])

Fig. 9. 30-kVA transformer transfer impedance as in [7]

In the Fig. 9. Characteristic impedance is for 30-kVA transformer tested in Brazil. F_1 is occurring below bandwidth. Therefore, there is only single dominating frequency, which is high frequency.

It is the key indicating fact that in Fig. 8. at low frequency, capacitive response is very low and inductive is dominating; ultimately means that this frequency resonate the core in a very short band width. F_1 contains low magnitude and shorter band of frequencies having a less incorporation in the core resonating response. So this frequency will not affect the response of core and only one high frequency is dominating which validates the proposed concept.

CONCLUSION

The transformer models, which were investigated in previous research, were of 30 kVA, 50 kVA and 100 kVA. It was come into consideration that the discussions on those Transformer models was based on winding and were tested at no load condition. However, in this paper, the Transformer model of 50 kVA was selected and tested at load and no load conditions considering transformer rating and focusing on the core of a transformer. After theoretical analysis of past researches and experimental study of 50-kVA transformer, it is concluded that at 50 kVA and less ratings transformer core resonates at single frequency but above 50 kVA to higher ratings transformers core resonates two times. The model studied in literature investigation also validates the results of the model discussed in this paper. Proposed technique can be used in neural network to specify the specimen and patterns with respect to the characteristics frequencies to define the actual condition of the transformer in term of aging and efficiency.

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Haseeb Faisal received his BS Degree from COMSATS University Islamabad and currently persuing his MSc. Degree from Wah Engineering College. He is a research fellow at HITEC University Taxila. His major field of interest are High Voltage and Dielectrics materials.

Kashif Imdad received his BSc. Degree from UET Peshawer and then MSc. Degree from UET Taxila. He completed his PhD from Universitat Politècnica de Catalunya, Spain. Currently, serving HITEC University Taxila as an Assistant Professor. His major field of interest are High Voltage, Electrical Power Systems and Dielectrics.

Najeeb Hussain received his BS degree from HITEC University Taxila. He is attached with industry from Past two years.

Faisal Sharif BSc.(Pb), BS Engg. (Electr). Currently he is serving WAPDA as an Executive Engineer. He has an experience in Power Operations, maintenance and distribution.