3rd International Conference on Engineering and ICT (ICEI2012)
Melaka, Malaysia
4 – 6 April 2012

MECHANICAL CONDITION ASSESSMENT OF TNB IN-SERVICE DISTRIBUTION TRANSFORMERS USING SWEEP FREQUENCY RESPONSE ANALYSIS (SFRA)

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Abstract

Distribution transformers in TNB (Tenaga Nasional Berhad) are exposed to the thermal and electrical stresses. Those stresses are effecting to the main mechanical active parts in transformer such as core and winding. In field, lightning strikes and cable faults may cause problem due to transformer core and winding. Sweep Frequency Response Analysis (SFRA) is an off-line diagnostic tool used for finding out any possible winding displacement or mechanical deterioration inside the transformer especially core and winding. SFRA diagnosis is made based on the comparison between two SFRA responses and any significant difference in low, middle and high frequency sub-bands region would potentially indicate mechanical or electrical problem to the winding and core of transformer. The aim of this paper is to assess the condition of TNB in-service distribution transformers by using SFRA method.

***Keywords*—Winding Deformations, Dissolved Gas Analysis, Power Transformer, Sweep Frequency Response Analysis (SFRA)**

I. INTRODUCTION

There are varieties of faults conditions occur in power system networks such as lightning strikes, switching transients, cable strikes, apparatus failures and other incidents [1]. These faults will develop short-circuit current to be experienced by the apparatus in the power system network such as power transformer, three-phase motor and three-phase generator [2]. Power transformers are designed to adapt or withstand this short-circuit current, but the strong electrodynamics forces resulting from short-circuit can give defects to the transformer windings and core [3]. In the power transformer, the active part where the transformation takes place consists of core and winding [4]. Hence, serious attention is needed by the asset management to have monitoring systems for fault diagnosis to the power transformers whether it have suffered from the damage that could limit its lifetime and capability to withstand short-circuit current [4].

Fault diagnosis that have been used in power transformer are recovery voltage measurement (RVM), dissolved gas in oil analysis (DGA), and the frequency response analysis (FRA). RVM method is used to detect the conditions of oil-paper insulation and the water content of the insulation. In this method, a power transformer outage is required to carry out the test; meanwhile the test results give an indication of the state of the oil/paper insulation structure of the power transformer. However, the drawbacks in this method are a long outage may be required and the unreliability in the interpretation of the results [1]. DGA analyzes the percentages of ingredient gases in insulating oil, and provides the type of fault in power transformer according to the composition of gases. DGA has been widely used to periodically monitor status of power transformers. However, DGA is not capable of detecting precise electrical and/or mechanical faults, because they affect the dissolved oil in an indirect manner [5]. To overcome this limitation, FRA is capable for detecting failures in the core and winding geometries of power transformer [6]. There are two different methods used to carry out the FRA measurement: the sweep frequency response analysis (SFRA) and impulse frequency response analysis (IFRA) [3].

In this paper, the SFRA method is used because of it usage on detecting transformer winding deformation of TNB Distribution transformers [7]. SFRA method are generates magnitude and phase responses in frequency domains with measured input/output of voltage/current signals as shown in Figure 1[8].

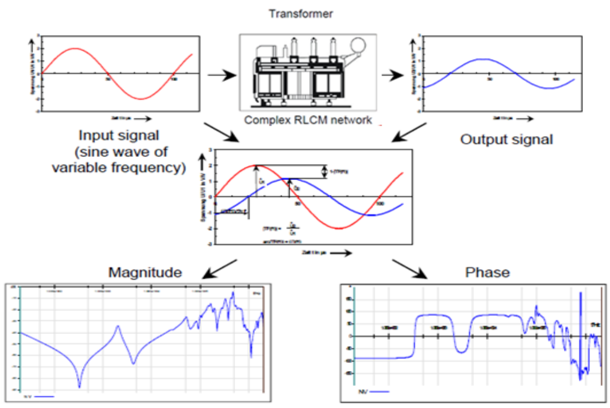

Figure 1. SFRA Concept of Measurement. [7]

SFRA method is purely a comparative method, which compares the measured responses with the reference fingerprints. However, the fingerprints are rarely available, especially in-service transformers. Thus other information (such as comparison between identically constructed transformers and comparison between phases inside transformer) has to be taken for diagnosis [12]. Figure 2, shows the comparison between SFRA measurement results of reference transformer and transformer under test. In general, the greater the difference between the two results, the greater movement in the transformer.

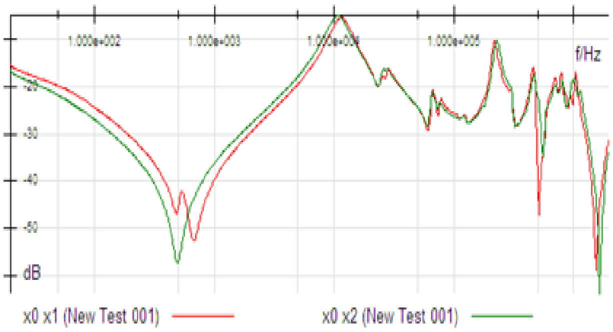

Figure 2. SFRA Measurement Results Comparison.

II. MEASUREMENT METHOD

The Omicron FRAnalyzer is a sweep frequency response analysis (SFRA) device that has been used for the diagnosis of mechanical movement in the TNB in-service transformers. Figure 3 shows the connection of Omicron FRAnalyzer to the tested transformer. The device generates a sinusoidal voltage at a selected frequency (from 20 Hz to 20 MHz) and measured the input voltages, amplitude and phase, on two input channels of "Reference" and "Measure". Subsequently, the transfer function is determined regarding to the ratio of input and output results and the common way of representing the transfer function is based on bode plot diagrams; where both magnitude and phase response are illustrated. In majority of studies, the magnitude response is commonly used on diagnosing and interprets the transformer problems [7-12].

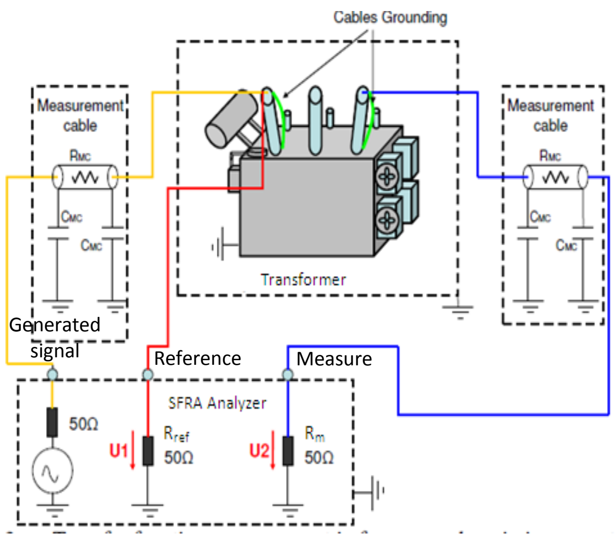

Figure 3. The Omicron FRAnalyzer Terminal Connection. [8]

III. FREQUENCY RANGES OF SFRA MEASUREMENT

The magnitude response of a tested transformer gained from SFRA is basically in frequency domain, which means that each ranges of frequency are related to the transformer transfer function. The transfer function itself indicates the response from each complex parameter inside the transformer. The sweep frequency generated is between 20 Hz and 20 MHz. For the application of transformer mechanical movement detection especially core and winding, these frequency ranges are used according to Table 1 [5]-[8].

Table 1. Frequency Ranges Used in SFRA Measurement Interpretation.

Frequency Ranges	Sensitive to Elements
Below to 10 kHz	In this range phenomena linked with the transformer core and magnetic circuits are found.
10 kHz to 500 kHz	In this range phenomena linked with radial relative geometrical movements between windings are detected.
200 kHz to 1 MHz	In this range axial deformations of each single winding are detectable.

IV. RESULTS AND DISCUSSION

In this paper, the results and discussions are discussed based on SFRA results from TNB in-service distribution transformers at PPU Seksyen 23 Shah Alam 30MVA 33/11kV Dyn11. The transformer has been in-service for almost 18 years and tripped on Buchholtz and Differential which suggested the occurrence of internal fault [13]. This is supported by DGA where results showed the occurrence of High Energy Arcing with little involvement of paper. The SFRA measurement carried out on both HV and LV windings. The comparisons of the SFRA measurement results are done by using symmetrical winding comparison type. Figure 4 and 5 are related to the HV winding phase comparison. Meanwhile Figure 6 and 7 are based on LV winding phase comparison. In Figure 4, from the comparison between SFRA graphical result of H1H2 phase to H3H1 phase shows no such deviation occurs for overall frequency ranges. It means no mechanical deformation regarding to both core and HV winding in H1H2 phase and H3H1 phase. Meantime, in Figure 5 shows the comparison of SFRA graphical result in H1H2 phase to H2H3 phase. As it can be seen, comparison for these two curves in HV winding is having a huge changes or different in low and high frequency range which indicate a defect or problem related to the mechanical condition in transformer core and winding at the middle limb.

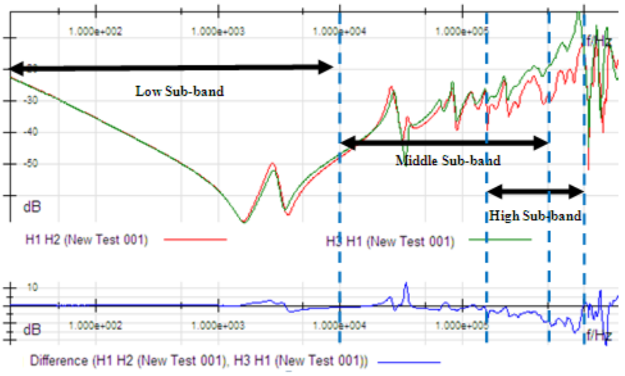

Figure 4. SFRA measurement results for HV winding (H1H2 phase compared to H3H1 phase).

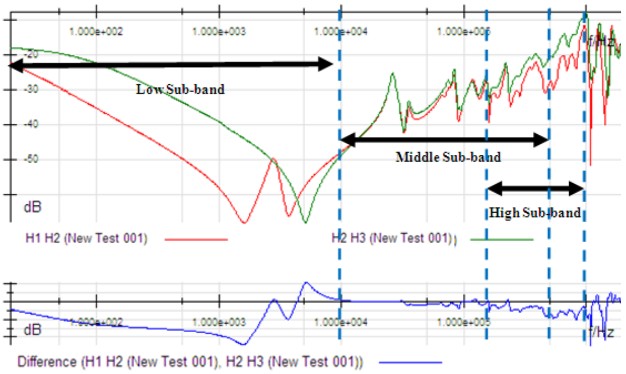

Figure 5. SFRA measurement results for HV winding (H1H2 phase compared to H2H3 phase).

In Figure 6, from the comparison between SFRA graphical result of x0x1 phase to x0x3 phase shows no such deviation occurs for overall frequency ranges. It means no mechanical deformation regarding to both core and LV winding in x0x1 phase to x0x3 phase (transformer outer limb). For Figure 7 it shows the comparison of SFRA graphical result in x0x1 phase to x0x2 phase. The changes only occur in low frequency range and the affected part is in transformer core (middle limb) but not the winding.

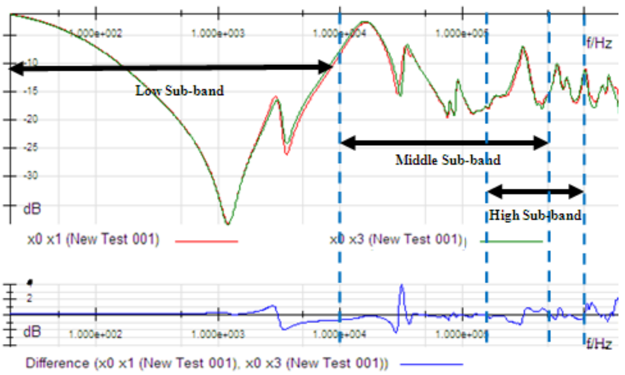

Figure 6. SFRA measurement results for LV winding (x0x1 phase compared to x0x3 phase).

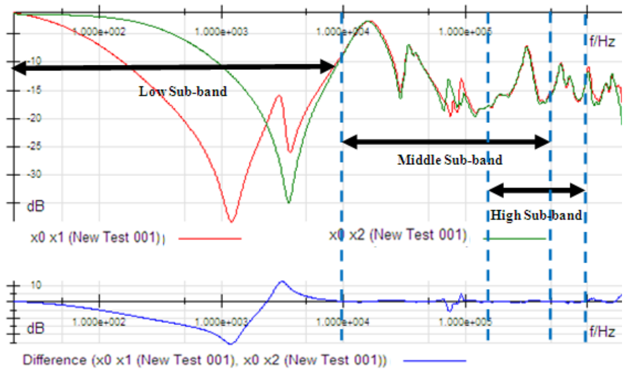

Figure 7. SFRA measurement results for LV winding (x0x1 phase compared to x0x2 phase).

V. CONCLUSIONS

In this paper, the SFRA method on diagnosing the condition of transformer main mechanical parts such as core and winding are shown. The research work is using the data from TNB in-service transformer. By using the phase comparison between HV and also LV winding it could be the best alternative way on interpret the SFRA measurement data besides on finding the transformer historical SFRA measurement data. In the next paper produced in the future may have the visual inspection inside the tested transformer to prove the finding made by SFRA measurement results.

VI. ACKNOWLEDGEMENT

The authors gratefully acknowledge the reviewers of this paper for their valuable advice and guidance. The authors also appreciate to M. T. Yasmin, PhD and Y. G. Young Ghazali for their best supervising on conducting this research project.

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