On line analysis of short circuit tests on windings

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Abstract—Short circuit currents in two windings transformers can cause winding deformation. While the conventional test involves the measurement of reactance before and after the test, we propose an on line measurement. The method is demonstrated by static and dynamic tests on a specifically designed voltage transformer. The shape of excitation is tailored to maximize its signal to noise ratio for deformation detection.

Keywords: Transformer, Short circuit, winding displacement.

I. Introduction

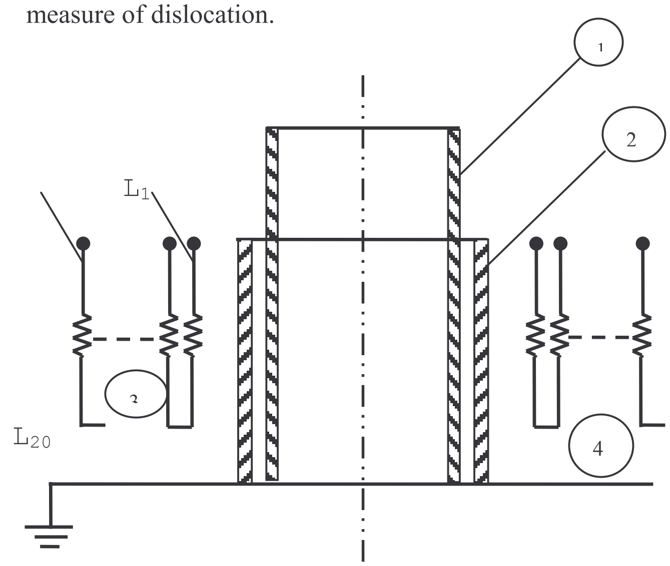
The short circuit test on transformers is a special test as described in IEC60076-5.For two winding transformers of category 1, three tests of 0.5 s each are required to be performed. The short circuit test is equally valid for voltage transformers to IEC-60186. Conventional methods of fault detections as a result of the tests are based on measurement of reactance or errors. Recently efforts have been made to use the frequency response techniques, transfer function analysis etc [1], [2]. All these methods are based on separate tests conducted after the short circuit test. This paper investigates online analysis of short circuit test by injecting low voltage impulse concurrently with power frequency current in order that changes in the winding can be monitored throughout the duration of the test.

II. Device under TEST AND methodology

A 6.6 kV single-phase voltage transformer is the device under test. It comprises of 20 layers (L1-L20) with 250 turns /layer wound on a former of diameter 98 mm. The winding length was 100 mm. A round metallic tube of 80mm diameter and 340 mm length served as a short-circuited secondary winding. All experiments were performed with the DUT in a vertical position and distances are measured with respect to a reference plane at 0 mm. The motivations for using the voltage transformer were as follows:

- It comprises a layer winding which is also used in large power transformers
- A short circuit test is prescribed for VTs.
- The topology of the winding is substantially the same from 6.6 kV to 400 kV
- Its dimensions are compact

The schematic of the winding is shown in Fig. 1 while Fig. 2 shows its photograph. In order to demonstrate the sensitivity of the impulse excitation method, experiments are conducted in a sequential manner as follows. The principle of the method is demonstrated using a static approach. Here the inner tube is raised at finite intervals from the reference plane. The VT is energized with impulse excitation at each level. The changes in the frequency response of the winding current serve as a measure of dislocation.



1. Metal Tube 2. Former for Primary winding
3. Primary winding L_1–L_{20} 4. Reference plane

Fig. 1 Schematic diagram of 6.6 kV VT

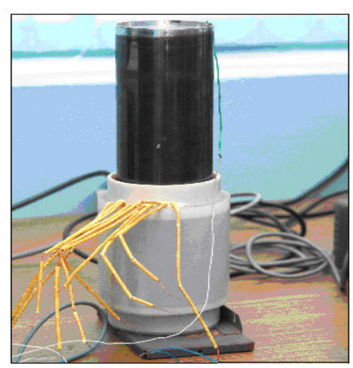


Fig. 2 Photograph of 6.6 kV VT

In order to demonstrate the dynamic sensitivity, which is the main feature of the work, the secondary is moved from a

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finite height and a sequence of impulse voltages applied during the movement. The changes in the frequency domain current again serve as a measure of dislocation.

III. STATIC SENSITIVITY WITH IMPULSE EXCITATION

Theoretically the frequency response could be obtained using a wide variety of wave shapes. For example, swept sine techniques or impulse voltages can be used. The choice of the type of wave shape is governed by the following:

- Frequency range of interest.
- Ease of hardware implementation.
- Signal to noise ratio of measurement.
- Sensitivity of the overall method to displacements
- An adaptive feature.

We begin with a frequency response measurement using a standard lightning impulse of 1.2 / 50 μs. A standard lightning impulse shape is initially used, as the hardware for generating such wave shapes is readily available in most testing laboratories. It is also known that the procedure for superimposing LI on a 50 Hz waveform is fairly old and was proposed by Hagengath [5]. Here we apply the signal through an arbitrary function generator. In practice, physical movements during short circuit and other changes arise as a result of the current through the winding. It would be in feasible to develop a method if actual currents were used for all experimentation. We hence pass a current sufficient for the sake of instrumentation, actual changes in the winding are made by physically moving them. This is reminiscent of the synthetic injection test in circuit breakers where voltage and current are separately applied. An arbitrary function generator 33120A from Agilent is programmed to provide this voltage. The impulse is applied across the winding and the current measured through a resistor. Fig. 3 shows the graph of voltage and Fig. 4 shows its frequency domain response. The frequency domain response is computed using MATLAB and has been normalized so that the maximum value is at 0 dB.

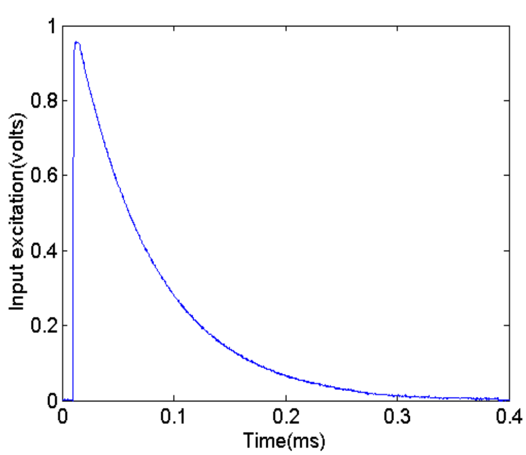

Fig. 3 Lightning impulse in time domain

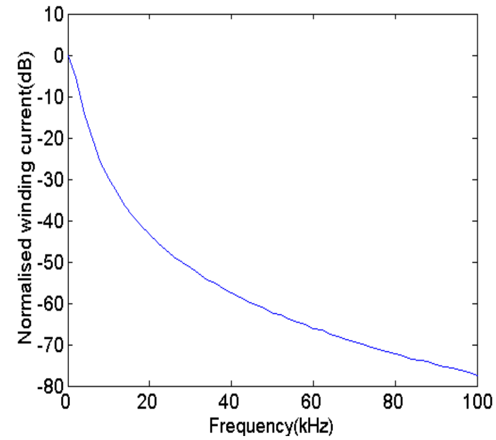

Fig. 4 Lightning impulse in frequency domain.

The corresponding winding current in the time domain is shown in Fig. 5 and its response in frequency domain is shown in Fig. 6 It can be seen that the predominant resonant frequency is at 54 kHz whereas smaller ones are at 23.4 kHz and 35.8 kHz

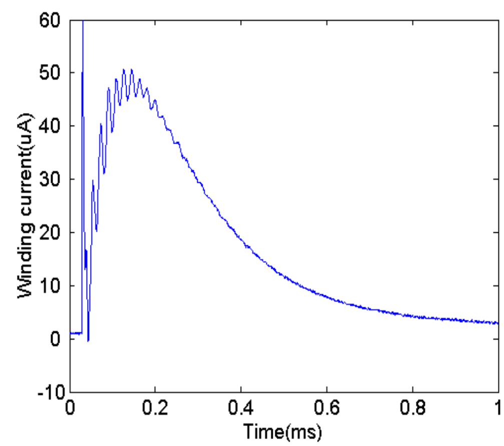

Fig. 5 Time domain response of winding current with LI input.

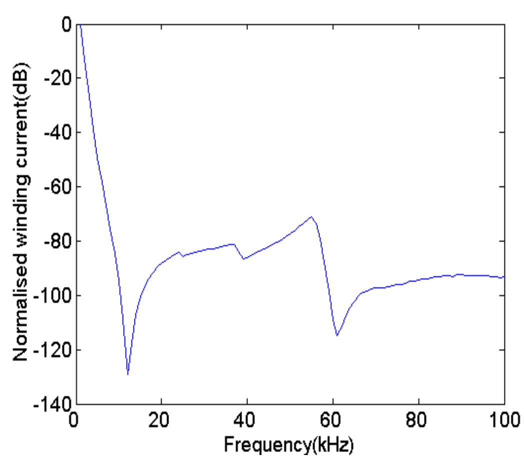

Fig. 6 Winding current in frequency domain.

If the inner metallic tube is shifted in the vertical direction and the displacements are given with the impulse applied, the time domain response for various displacements is shown in Fig. 7 and Fig. 8 shows its corresponding response in frequency domain.

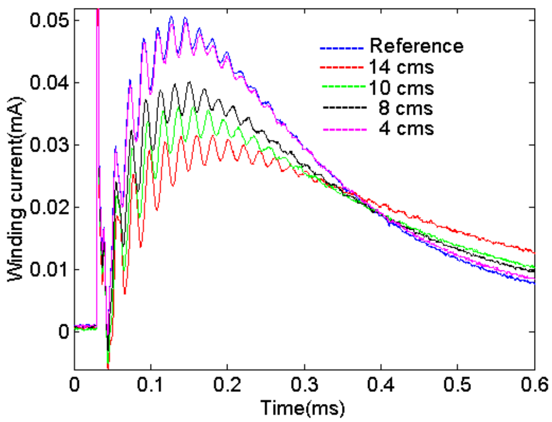

Fig. 7 Time domain response of winding current with variation in heights.

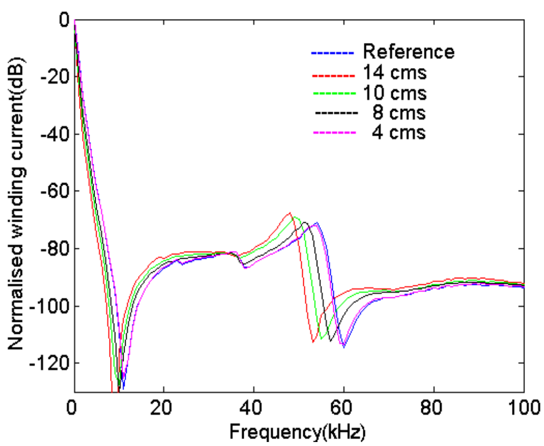

Fig. 8 Frequency domain response of winding current with variation in heights.

IV. Dynamic Sensitivity of the Impulse Excitation Method

The earlier section established the principle of the impulse excitation method. In order to establish the dynamic sensitivity of the method, the experiment is performed as follows. The inner tube is raised to a height of 140mm. While it is dropped from this height a series of lightning impulse voltages are applied to the VT. The changes in the frequency domain are then established. Fig. 9 shows the applied voltage and Fig. 10 the time domain response of winding current from impulse1 to impuse3.

Fig. 11 shows its corresponding frequency domain response.

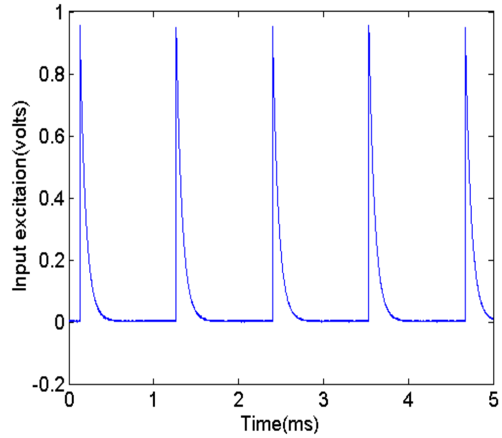

Fig. 9 Time domain representation of series of lightning impulse voltages.

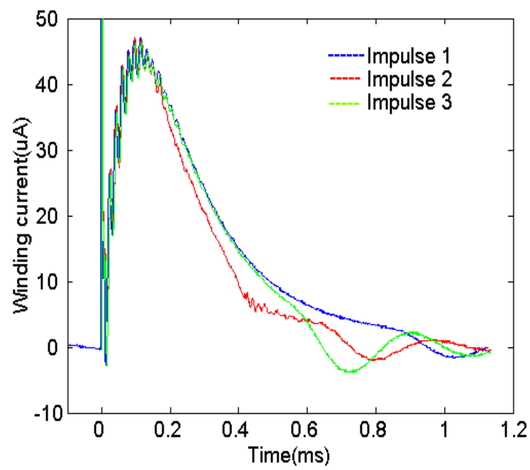

Fig. 10 Time domain response of winding current

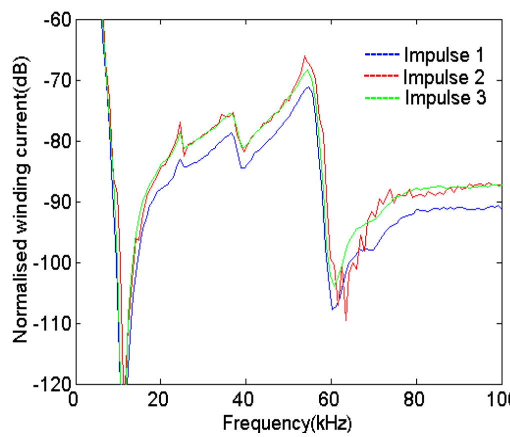

Fig. 11 Frequency domain response of winding current under dynamic test (impulse 1 to impulse 3)

V. A DICTIONARY OF FAULTS

Short circuit testing of transformers have a long history and it is evident that the archives of most test laboratories would have several classes of failure. It is suggested that a dictionary of such faults be created. For example, Karsai [4] mentions that the inner winding could take the form of Fig. 12 under buckling. The two cases correspond to inner coil buckling along two axes and one axis respectively. The plan view of the winding with spacers is shown.

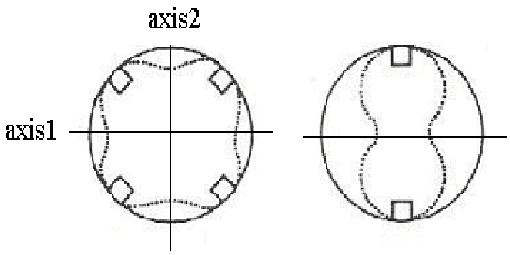

Fig. 12 Schematic diagram of winding deformation due to buckling.

In order to simulate such a condition, a single outer layer is added to the VT. Fig. 13 and Fig. 14 shows the frequency response of the winding current for series of lightning impulse with buckling along axis1 and axis2 respectively. The changes are small in the region of –70 dB.

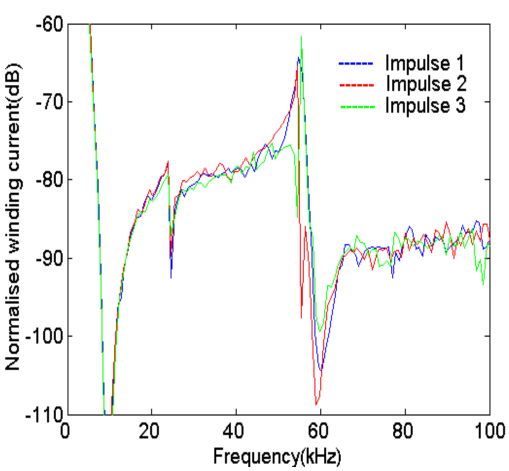

Fig. 13 Winding current in frequency domain for buckling along axis1under dynamic test (impulse 1 to impulse 3)

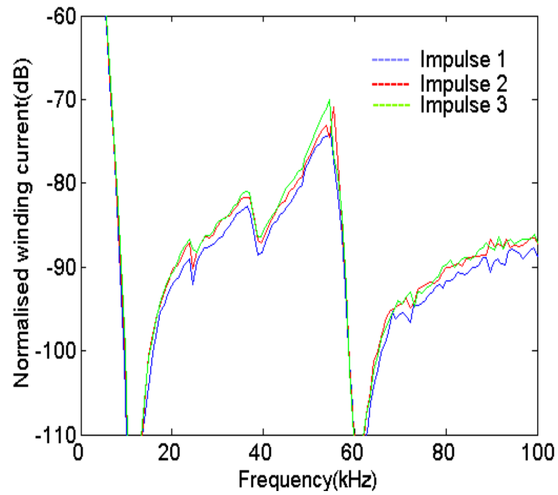

Fig. 14 Winding current in frequency domain for buckling along axis1 and axis2 under dynamic test (impulse 1 to impulse 3)

VI. VALIDATION OF RESULTS ON A POWER TRANSFORMER

It is standard manufacturing practice to tighten the bolts that compress windings after drying the coil prior to the ingress of oil in the tank. This provides a good case study for the utility of the impulse excitation method. Fig. 15 shows a 33 kV / 11 kV 10 MVA transformer with bolt locations highlighted. Impulse voltages were applied at the start of the tightening and finally after tightening by 20 mm. The frequency responses are shown in Fig.16. It is observed that at 723 kHz the change is 4 dB and at 783 kHz the change is 2 dB.

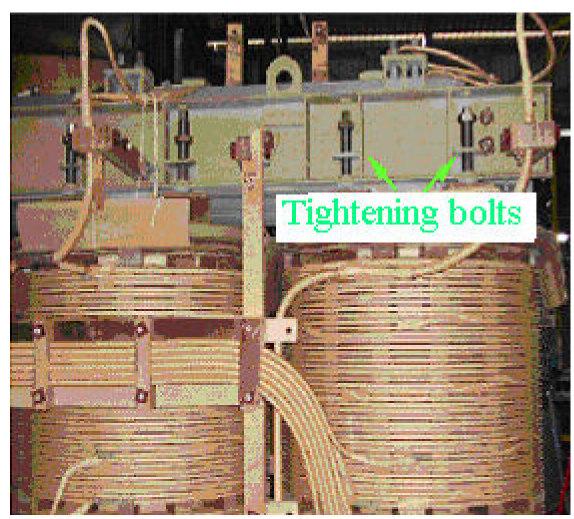

Fig. 15 Photograph of the winding

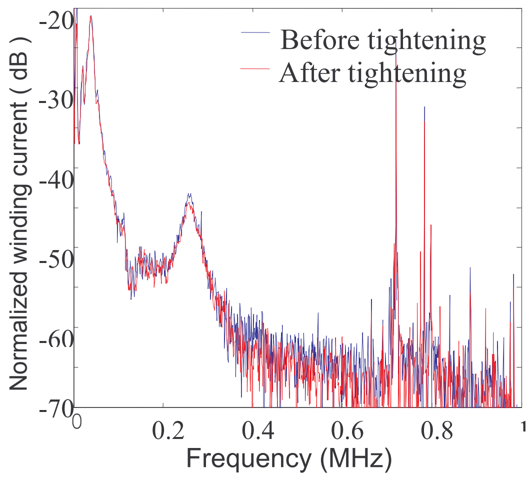

Fig .16 Winding current response in frequency domain

The changes in dB are observed only in the high frequency region, which is dominated by noise. Due to the difficulty in identifying the change, alternate excitations are proposed for the analysis of winding deformations.

VII. ALTERNATE EXCITATIONS FOR WINDING DISPLACEMENT DETECTION

From Fig. 8 and Fig. 16 it is evident that gross movement can be easily detected and it is also evident that the standard lightning impulse voltage produces a response with a signal to noise ratio that is not uniform over the spectrum. It would be convenient to device a wave shape that provides a better SNR at the significant resonant frequency. A waveform that suggests itself is the oscillating impulse voltage. This comprises a standard lightning with a superimposed sinusoid corresponding to the resonant frequency of interest. This can be generated in the Marx circuit with suitable inductance in series with front resistor. Accordingly a waveform as shown in Fig. 17 is generated using the arbitrary function generator. The corresponding time domain response of winding current is shown in Fig.18.Results using this waveform is described in [4]. The second waveform that was considered is a chirp waveform with the frequency being swept from 30 kHz to 80 kHz and a sweep rate of 1ms.With the chirp waveform a time frequency analysis tool such as the Wigner-Ville transform is also feasible [4]. Fig. 19 and Fig. 20 show the chirp excitation and the corresponding winding current in frequency domain. Fig. 21 shows the WVD response of a series of 10 chirp signals obtained when the secondary of the VT was dynamically moved. Fourier analysis of each chirp as well as WVD show comparable results.

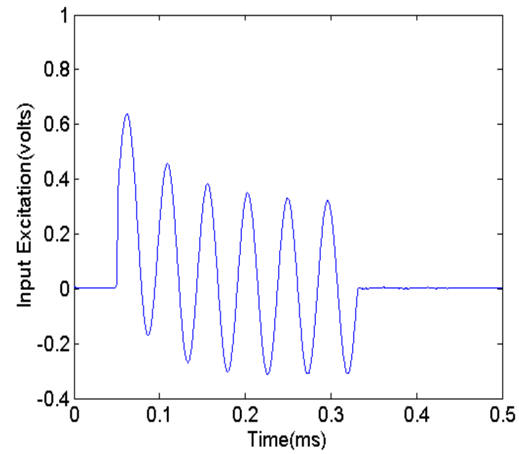

Fig. 17 Oscillating impulse voltage in time

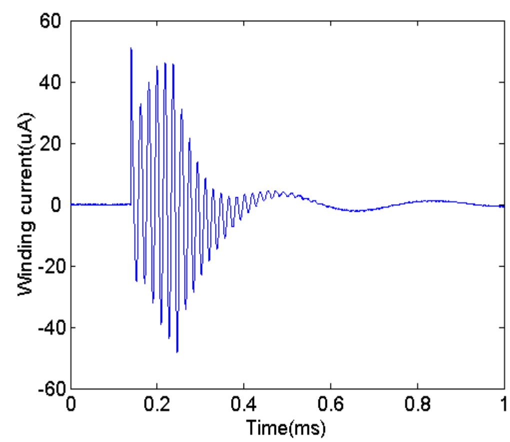

Fig. 18 Time domain response of winding current with oscillating impulse voltage.

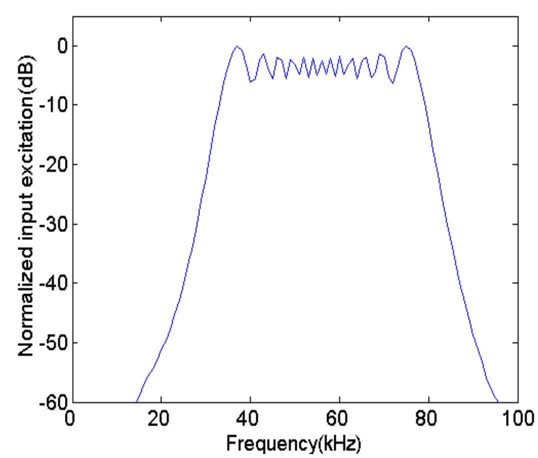

Fig. 19 Chirp excitation in frequency domain.

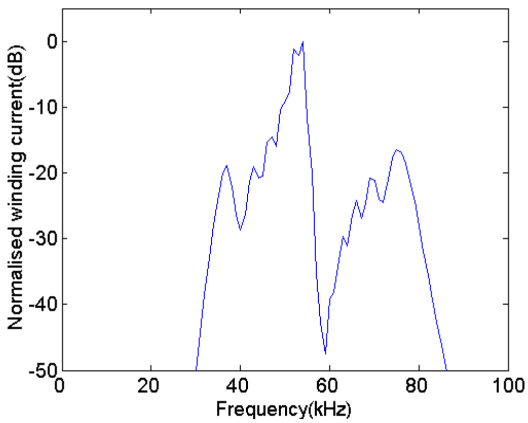

Fig.20 Winding current with Chirp excitation in frequency domain.

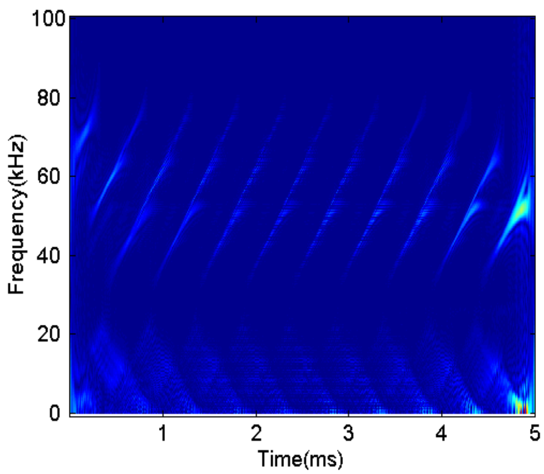

Fig. 21 WVD of winding current with Chirp excitation

The signal to noise ratio of the responses with each of LI, oscillating impulse and chirp inputs are calculated as 35.2 dB, 38.6 dB and 49.7 dB respectively.

VIII. COMBINED EXCITATION

The proposed method in the final form involves the application of the impulse voltage concurrently with the power frequency excitation. The point of injecting the impulse voltage is when the power frequency current approaches zero. In order to observe the two signals at different sampling rates it would be possible to design an instrumentation scheme that is based on separate A/D converters for each signal. Thus the sampling rate for the 50 Hz signal can be of the order of a few kHz while that of the impulse voltage could be of the order of 10 MHz. A second option is to use a recorder with this feature. The Yokogawa DL750 scope recorder has a dual capture feature with this function. Separate records are not shown as the waveforms in the case of the figures shown above is based on a sampling of 10 Ms/s with 12-bit accuracy. In practice, the choice of the oscillating frequency of the impulse voltage can be determined by sensitivity studies on the model of the winding. Several methods for modeling winding responses to LI [6] are available and hence not repeated here.

IX. CONCLUSION

A method has been suggested for on-line analysis of short circuit tests in windings. It involved the application of a lightning impulse voltage concurrently with the power frequency voltage. Experimental results confirming the validity of the method were shown on a voltage transformer and a power transformer. It is possible to analyse winding displacements as well as buckling based on the tests.

X. ACKNOWLEDGEMENT

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XI. REFERENCES

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XII. BIOGRAPHY

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