

Transient fault Detection and Analysis of Distribution Transformers using Transform based Techniques

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Abstract: *Efficient fault detection of distribution transformers has great worth when installation of distribution transformers in the field is taken into account. Computer software has been developed which makes it possible to detect the region of fault location and evaluate the strength of insulation puncturing. It has the capability of locating the position of fault along with total percentage of insulation breakdown region. Different evaluation tests are performed which are capable to recognize not only the visible faults but also those faults in the windings of distribution transformers which are Incipient. Such kinds of faults in transformers generally pass the impulse test but when the transformers installed into the field they are subjected to cause the insulation failure of their windings. Evaluation techniques of the research project remarkably cop up with such kind of insulation breakdowns and present a good quality approach of evaluation for the undesired dominant frequencies. With the help of this research a new method of impulse testing can be introduced in the field of high voltage testing. The scope of this research project is to facilitate the transformer designers and manufacturers to improve their designing techniques of insulations which is not yet introduced. Furthermore it also evaluates the incipient and solid faults in transformers that are not visible by inspection.*

Key Words: *Impulse test; insulation failure; wavelet analysis, wave-front time, wave-tail time*

1. Introduction

Distribution transformers are tested in the high voltage laboratory before their installation into the field because there is always a chance of insulation failure especially in the windings of transformer. The term insulation failure refers to the breakdown of insulation in transformer due to high voltage surges causes due to switching operations and lightning strokes. In order to detect the fault efficiently and to

analyze the fault location, it is necessary to have complete knowledge of 11kV line to 415 Volts distribution transformer which are normally of 25, 60, 100, 160, 200, 250, 315, 400, 500, 630, 750, 1000, 1250, 1500, 2000, 2500 kVA ratings, according to IS-2026 standard [1]. Testing of distribution transformers is performed at the high voltage lab to check the endurance of insulation. It has been observed that lightning strokes and switching operations are always followed by a wave of steep wave-front which causes an unequal stress distribution along the windings of the distribution transformers and ultimately cause the insulation breakdown of windings of the transformers. It is very important to perform impulse testing on distribution transformers before their installation into the power system so that any sort of discrepancy can be avoided. To test the transformers, high voltage transient is required which is generated by the impulse generator. Impulse generator generate the impulse who has the resemblance with the transient developed due to the switching operation and lightning strokes. The impulse is then applied on the distribution transformer under test, the schedule of impulse applied on the distribution transformer is as follows;

- a. One 75 % full wave impulse test, followed by
- b. One 100 % full wave impulse test, followed by
- c. One 75 % full wave impulse test, followed by
- d. Two 115 % chopped wave impulse tests, followed by

- e. Two 100 % full wave impulse tests
- f. One 75 % full wave impulse test

Remaining paper is organized as follows; section II contains impulse testing practical approach with simulated impulse waveform, section III describes test results with Fast Fourier transform, section IV depicts the analytical techniques using wavelet transform to determine the insulation failure faults, section V describes the analysis of Incipient faults and section VI finally gives the future recommendations followed by the list of references used in this paper.

2. Impulse Testing and Wave Simulation

It has been observed while testing is performed on transformer, majority of faults occur belong to the solid insulation puncture or breakdown of the windings insulation and it is also found that due to high dielectric strength of oils, insulation breakdown of oil is very rare especially in countries like Pakistan. If transformer with good insulation as per design standard is tested for transient overvoltage, will let the complete wave to pass through while transformers with weak insulation will present abnormal wave cutting abruptly to the time axes as shown in test result section. This abnormal behavior of wave will practically impose black spots on transformer windings under test.

a. Impulse waveshape

The values of impulse generator parameters are adjusted in such a way that the shape of impulse used for simulation may follow specifications of International Electro-Technical Commission (IEC) or the British standard B.S. 923 with wave-front and tail value 1/50 μ sec or 1.2/50 μ sec. This wave is generated for simulation is shown in fig.1. The wave-front time is calculated as $(t_3 - t_1) / (0.9 - 0.1)$ or $1.25 (t_3 - t_1)$ for the 10% to 90% measurement where t_3 is the time to reach at the 90% peak level of impulse and t_1 is the time to reach at the 10% peak level of the impulse, $(t_3 - t_2) / (0.9 - 0.3)$ or $1.67 (t_3 - t_2)$ for the 30% to 90% measurement.

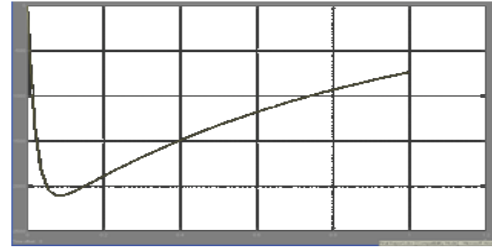


Fig. 1. Impulse according to B.S. 923, 1.2/50 μ sec

b. Length of Windings based Fault analysis

Initial step of transformer testing as per IEC standard is the application of 95kV impulse on three phases of transformer under test followed by test pattern of applying 60kV and 120 kV chop etc., to verify the surge withstand capability of transformer windings prior to their installation in the field. 95kV impulse without any fault is generated for simulation purpose as shown in fig 2 (a). Fig 2 (b) represents impulse wave when transformer is subjected to insulation failure.

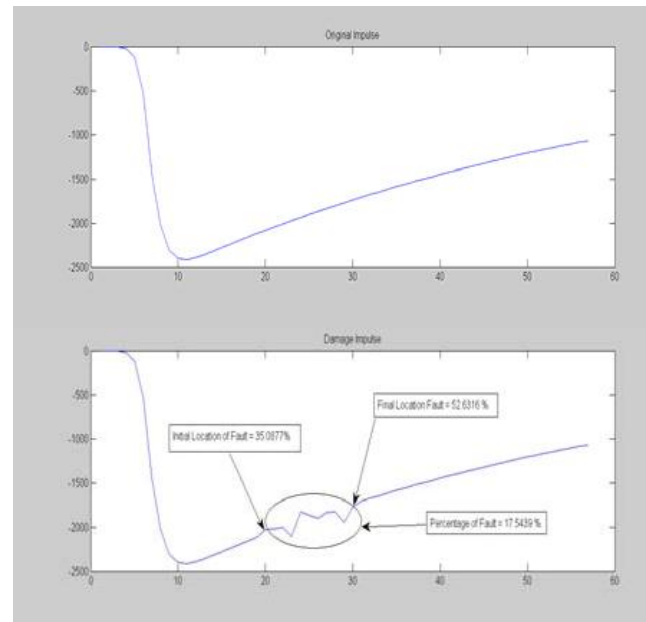


Fig. 2. (a) Impulse without fault (b) Faulty impulse

After physical inspection of faulty distribution transformer, a simulation method is devised to approximate the location and type of fault depending upon the fault severity. For the experimental purpose, intentional fault in the windings is introduced. The

developed software interprets the fault and gives results of initial and final location of fault and total percentage of faulty windings as given below;

Initial location of fault = 35.0877 % length of windings

Final location of fault = 52.6316 % length of windings

Total percentage of fault = 17.5439 % of total length

3. Test Results

Figure 3 shows the four different approaches to understand the behavior of faulty impulse by using stair case analysis, stem analysis, ribbon analysis and waterfall analysis. Looking at stair case analysis it can be observed that at the damaged portion of impulse stairs sizes become larger than its routine response. Ribbon analysis and waterfall analysis present the 3- D view of the impulse.

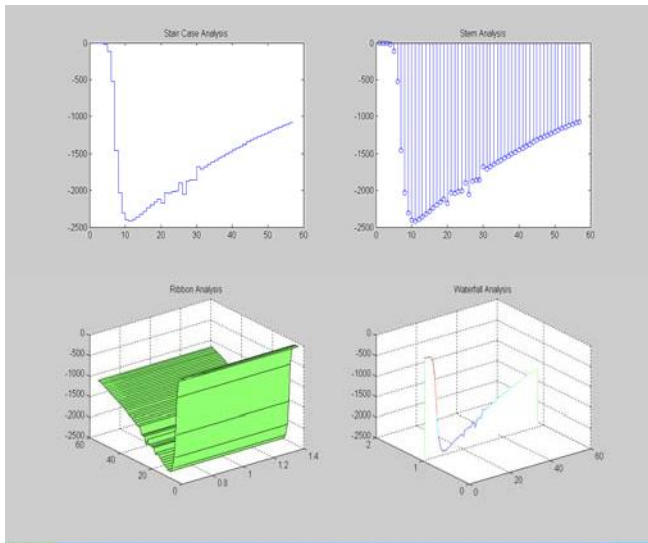


Fig. 3. Stair case, stem, ribbon (3-D) and waterfall (3-D) Analysis

a. FFT Analysis

A common use of Fourier transforms is to find the frequency components of a signal buried in a noisy time domain signal. FFT converts the time domain impulse to the relative frequency domain. For the transient voltage failure, the dominant frequency at that moment plays an important role for the designers. It is most important to evaluate

the type and location of fault at approximate length of windings depending upon the frequency spikes. For the better understanding of the faulty region FFT analysis is performed. Fourier transform is suitable for stationary signal analysis. In this analysis for fault detection in distribution transformer, impulse wave is considered as stationary in nature which can be evaluated by FFT analysis that is sufficient to extract reliable results.

Figure 4 and 5 present the FFT analysis of impulse without fault and faulty impulse. Careful investigation of both figures reveals the difference between spectral densities of faulty and wave without fault. It is found that the decrease in power spectral density is not gradual in the FFT analysis of faulty impulse as compared to the FFT analysis of impulse without fault whose decrease in power spectral density is gradual and hump vanishes with rise in frequency. The abnormal power spectral density humps at the frequencies 250 Hz, 275 Hz, 300 Hz, 330 Hz and 370 Hz are found. 3-D response of wave in figure 4 and 5 shows the difference in humps at higher frequency points while the response is found same at low frequency.

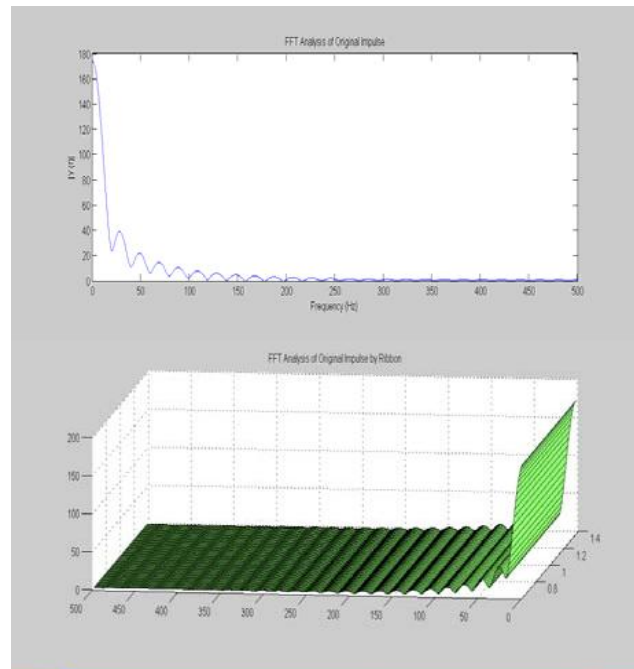


Fig. 4. FFT of unidirectional impulse without fault

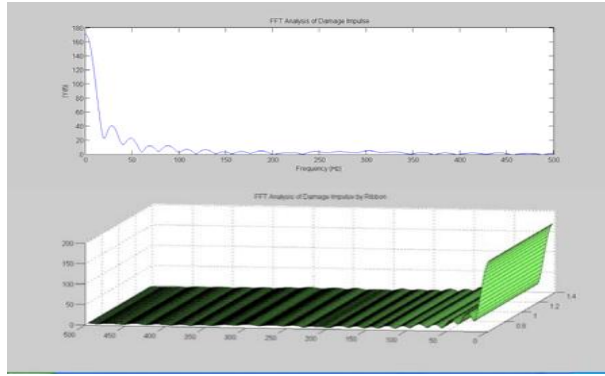


Fig. 5. FFT of unidirectional impulse with insulation fault

b. FFT Analysis of various insulation faults

Complete failure in the windings of transformers is caused by the extremely low impedance due to gradual aging effect. Non standard clearance between two conducting paths and between conductor and transformer wall may also cause complete short circuit. Another reason is the presence of unaddressed incipient fault which with the passage of time becomes solid fault and causes complete insulation failure. If windings of transformer are very old then they may subject to complete insulation failure due to rusting of the windings caused by oxidation of the transformer oil.

A 95KV impulse applied on one phase of distribution transformer under normal condition followed by complete insulation failure as given in Figure 6 and 7. Different graphical analysis techniques are applied to get more information to distinguish between faulty and healthy windings of transformer.

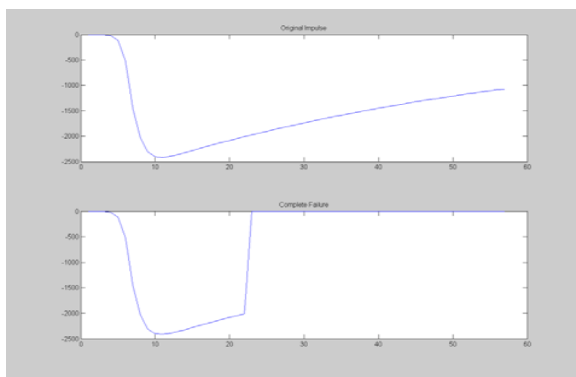


Fig. 6. Original Impulse and Complete Insulation

failure waveform

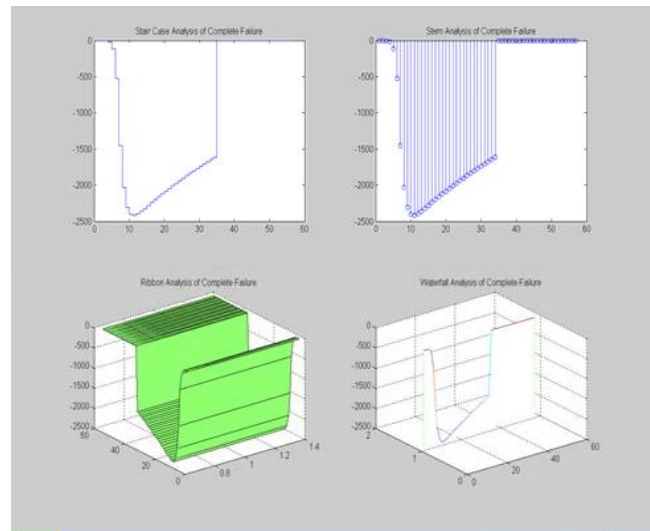


Fig. 7. Various representations of Complete Insulation failure

It is to be noted that FFT analysis although gives the required information of transient fault under prominent fault scenario like complete insulation failure etc., but confusion is faced when transformer windings encounters incipient fault like partial discharge or small leakage as shown in figure 8. The transformers pass the insulation test with such characteristics and can't be distinguished by FFT but ultimately cause solid fault when subjected to impulses after installation in field.

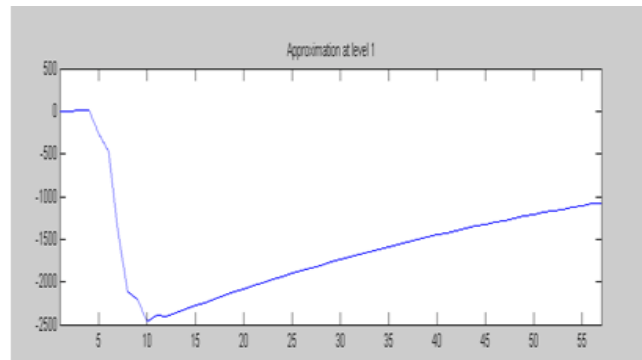


Fig. 8. Incipient fault due to winding Insulation leakage

This issue is seriously dealt and very reasonable solution is proposed in this paper. It has been observed that such faults are well addressed and recognized by using wavelet transform instead of fourier transform. Wavelet

transform is already recognized as superior technique to be applied in video compression where FFT fails. Next section describes the utilization of wavelet to recognize the incipient faults which are highly difficult to recognize through FFT.

4. Wavelet based Test Results

Wavelet transforms have the feature that they give better frequency resolution (but worse time resolution) at low frequencies and better time resolution (but worse frequency resolution) at high frequencies. This is in general desirable for most practical signals where higher frequency components tend to be short-lived whereas lower frequency components tend to be longer in duration [4]. Wavelet transform has its different levels, the use of which is case dependant. There are five different levels of wavelets, starting from level 1 to level 5; level 1 is the most compressed level of wavelet. The selection of wavelet family members is application dependant and is chosen on the basis of analysis requirements. In order to detect the faults in machinery, the Wavelet analysis has been discussed by a number of authors. Mohanty et al. have implemented the fault detection in a multistage gearbox by demodulation of motor current waveform, in which DWT was applied to the demodulated current signal for de-noising and removing the intervening neighboring features [5]. The stator current has been analyzed via wavelet packet decomposition to detect bearing defects by Levent Eren [6]. Wenyi Wang and Albert K. Wong presented a model-based technique for the detection and diagnosis of gear faults [7]. A method based on adaptive Morlet wavelet filter for the crack tooth of wind turbine gearbox has been proposed by Xingjia Yao [8]. A Wavelet analysis presents the different types of wavelet functions with three different scales.

At low frequencies higher scale is chosen because it provides the better analysis results at higher scale and at high frequencies low scale is selected for the same reason.

a. Wavelet Analysis of Impulse without Fault

Wavelet analysis of original impulse is performed in figure 9 by using wavelet type sym2 with level 4. The d1, d2, d3 and d4 are the number of iterations decompositions performed at level 4 and a4

is the approximation of signal. At level 4 analysis, the approximations are also iterated 4 times i.e. a1, a2, a3 and a4 and only one iteration is considered instead of number of approximations.

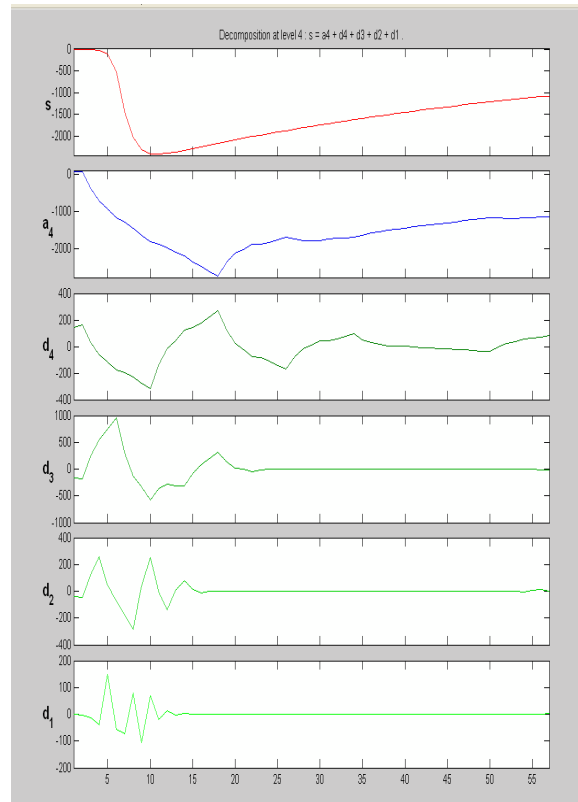


Fig. 9. Wavelet Analysis of Impulse without fault

b. Wavelet analysis of Faulty Impulse

It will be quite evident to compare graphs of faulty transformer windings with windings without fault, d1 and d2 levels will critically come up with the conclusion of recognizing the severity and location of fault. It is also noted, incipient faults can also be identified by inspection which is the key of this proposed paper. Next subsection will describe the importance of using wavelet transform for fault detection which is not possible with any other transform technique. Figure 10 wavelet sym2 with level 4 is faulty waveform which is not showing the complete insulation failure but insulation degradation due to partial discharges. Such fault does not show any prominent evidence of insulation failure or initialization of failure in the windings. Since wavelet transform is possessing superior detailed analysis resolution characteristics, has successfully

indicated the faulty position and severity by showing high spikes at the region where the insulation of transformer is found weak.

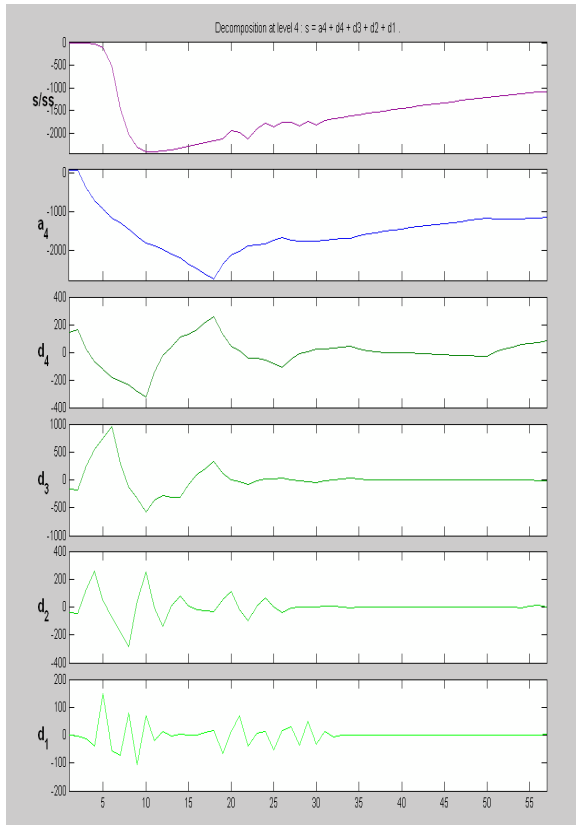


Fig. 10. Wavelet analysis of faulty impulse

Initial high spikes at points 4-11 on x-axis show the transition of impulse from wave front to wave-tail which is normal practice and is also seen in wave response of windings without fault. But spikes at detailed graph d1 is found approximately at the center which is not a normal practice It reveals us that insulation weakness is found at 50% windings point and remains for 20% length of windings.

c. Wavelet analysis of Faulty Impulse (Complete Failure)

Figure 11 depicts the effect of complete windings failure by using wavelet transform. Since complete windings failure can be evaluated from its occurrence in testing laboratory. But its wavelet analysis is also inevitable to investigate the various events and develop complete data base of faults. It is visible from the wave response that complete

failure causes the high spikes at 61% length of windings as shown in figure 11. There is new type of representation of data in the form of wavelet coefficient. It has been observed that when frequency variations take place, the magnitude of wavelet coefficient is increased. It has also been observed that in figure 11 that the region where frequency variation occurs, the high spikes are found and that is actually the region which corresponds to the region of maximum wavelet matching with the impulse.

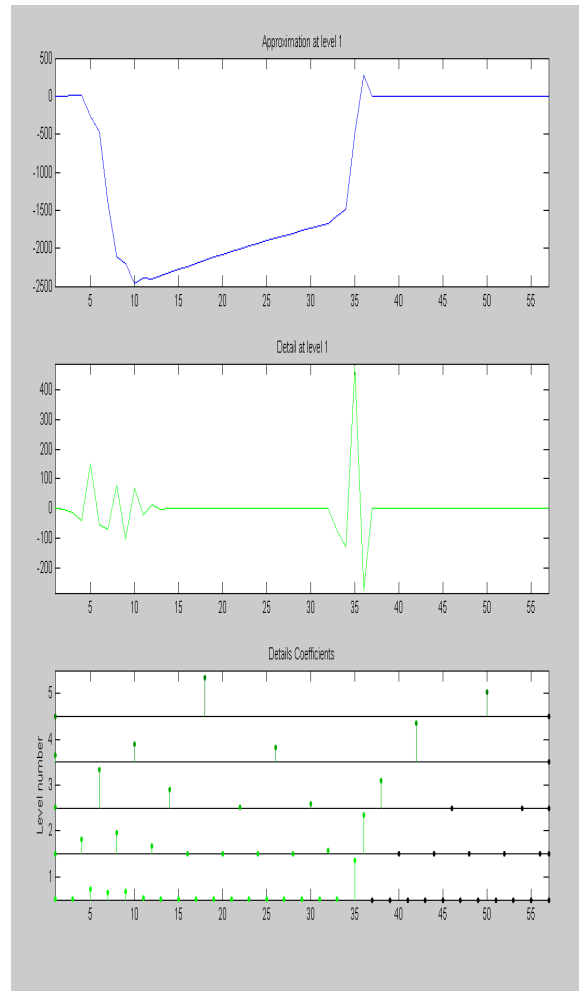


Fig. 11. Wavelet analysis of faulty impulse (Complete Failure)

d. Wavelet analysis of Faulty Impulse (110 kV Chop)

Chopped impulse testing is very important to apply on the transformer under test. This is a most severe test for the transformers because a high

voltage impulse is applied to the object under test which drastically becomes zero due to which possibility of insulation failure is highest. Figure 12 is illustrating the chopped impulse with a minute fault. Complete failure and chop wave resembles each other except the difference of magnitude between voltage values i.e., 95 kV and 110 kV. Wavelet transform of the two waves with more iteration will comprehensively detect the fault location and weak insulation point in transformer windings.

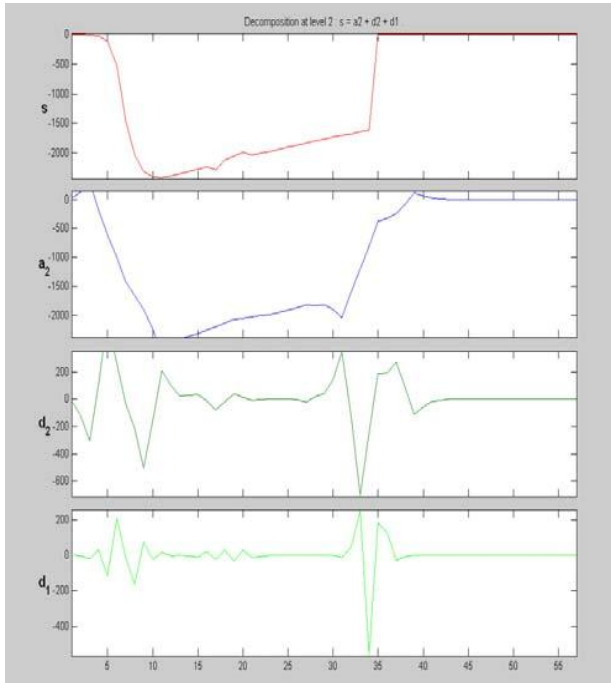


Fig. 12. 110 kV chop with incipient fault

5. Analysis of Incipient Faults

This section illustrates the most important area of research in the field of high voltage testing of equipments. When the tested transformers are installed into the field, sometimes they are subjected to cause the insulation failure after a very short span of time i.e; after one or two months. In such kind of cases actually transformers passes the test but in reality their insulation strength is not good enough to withstand the high voltage surges developed due to lightning strokes and switching operation. The analysis of such kind of faults is a challenge for the testing engineers. Figure 13 shows the different types of analysis for incipient faults occur in the windings of the transformer and it can be clearly observe that the region of faults cannot be captured or analyzed.

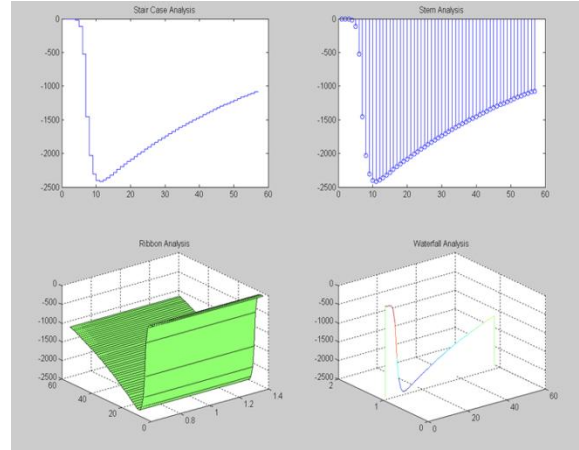


Fig. 13. Staircase, stem, ribbon (3-D) and waterfall (3-D) Analysis

a. FFT Analysis of Incipient Faults

FFT analysis of impulse without fault and impulse with Incipient fault has been performed so that the better analysis of impulse can be achieved. Figure 14 illustrates the FFT analysis of both impulses without fault and impulse with Incipient fault by 1-D and 3-D view. But one can still never be able to investigate and judge the area of fault occur in the impulse because when we compare the faulty/damaged impulse with the original impulse i.e; impulse without fault, no difference can be noticed, in fact both waveforms looks similar to each other.

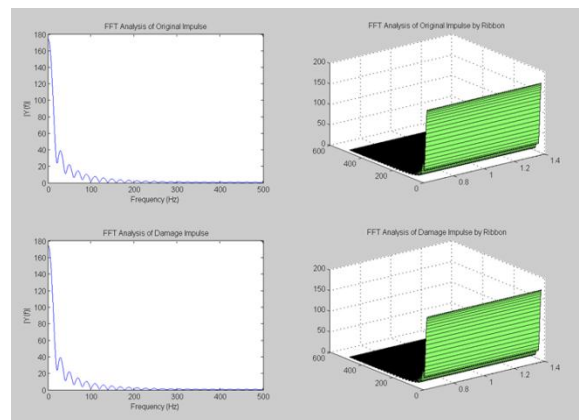


Fig. 14. FFT of unidirectional impulse without fault and with Incipient fault

b. Wavelet Analysis of Incipient Fault

After a careful investigation of impulse with

Incipient faults, remarkable results were achieved. Wavelet type coef1 level 2 has been applied for investigation of faults. Wavelet analysis of Incipient faults is shown in figure 15. In the figure shown waveform "s" represent the impulse to be analyzed for the investigation of fault, "a2" is the approximation of impulse and d1 and d2 are number of decompositions of analyzed impulse. The waveform d1 gives a perfect view for the evaluation of impulse; two partial discharges can clearly be seen in the form of low spikes at points 20-30 and 38-47 on x-axis. Actually these partial discharges cannot be captured in a normal fashion and are responsible to cause insulation failure of windings of the transformer in a short span of time after their installation into the field. A careful investigation is needed to perform which can be achieved by using Wavelet analysis as discussed.

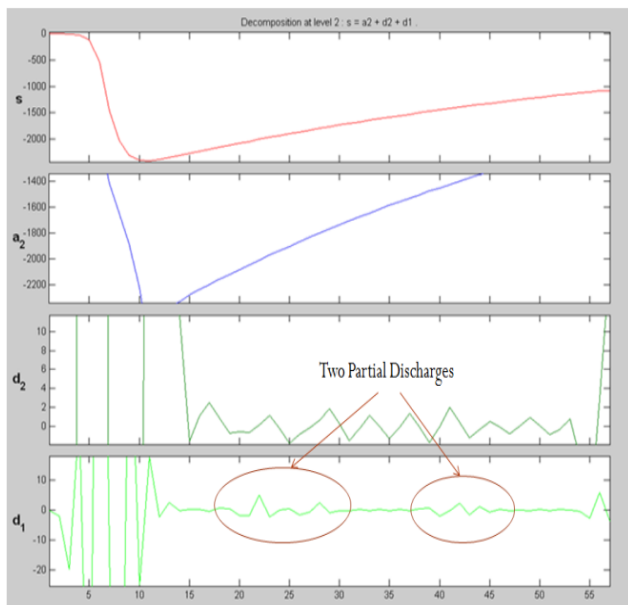


Fig. 15. Wavelet analysis of Incipient fault

6. Future Recommendations

A wavelet threshold is needed to settle on the basis of severity of fault, by doing this a fault severity level can be defined by the designers that will be helpful for the complete analysis of the fault. This will definitely improve the equipment testing methodology against lightning impulse.

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