Synopsis

Power transformers are important for stable and reliable operation of power supply systems. Being one among vital equipments, the failure of power transformer may cause serious outages and consequently have significant impact on economic operation of power systems. Insulation failure of transformer has been considered as one of the major causes of its breakdown and requires careful attention during design. After manufacturing, the integrity of winding insulation design is assessed by performing impulse testing as per standards. During impulse testing, propagation of high voltages surge along transformer winding results in failure of any improper/inadequate insulation in the winding.

Insulation failure may arise during impulse testing due to the defects which are present in the transformer insulation prior to the application of impulse sequences (improper insulation), i.e., the defects which were developed during manufacturing and not evolved during the propagation of impulse voltage through winding insulation. On the other hand, failure may evolve in winding insulation due to propagation of impulse voltage during impulse testing, i.e., due to inadequate insulation. These insulation failures are referred as static (improper insulation) and dynamic insulation failures (inadequate insulation), respectively.

In the case of dynamic insulation failures, amount of time required to establish complete insulation failure mainly depends on the condition of involved insulation, such as, moisture content and contaminations present in it. Higher the moisture content and contaminations in the insulation, sharper are the changes in the fault path resistance characteristics and lesser is the time required to establish complete insulation failure, i.e., fault establishment time (FET) is lower. On the other hand, less contaminated insulation has slow changes in fault path resistance characteristics and requires higher fault establishment time. Thus, different conditions of insulation require different FETs to establish complete insulation failure.

Various methods have been proposed by researchers in the past for identification and localization of insulation failures using acquired winding currents and the main drawback is that almost all of them
considered the insulation failure to be static in nature with fixed value of resistance (almost negligible value) of involved insulation at the time of insulation failure. It is well known that the winding parameters of the transformer will govern the temporal nature of the acquired winding current resulting from impulse excitation. From practical experience of impulse testing of transformer, it has been found that, this type of static or dynamic insulation failure change the nature of resulting winding current to certain extent. Impulse fault identification of previously proposed methods starting from study of oscilloscopic traces, are based on temporal nature of acquired winding current resulting from impulse excitation. This localization of insulation failures may not be realistic, because the nature of the winding current may vary to a certain extent for static and dynamic insulation failure. As a result of advancement in transformer manufacturing techniques, the defects in the winding insulation during manufacturing have been reduced significantly. So, the probability of occurrence of static insulation failure during impulse testing is presently less and majority of insulations that may arise are dynamic in nature. Hence, the identification of localization of dynamic insulation failure during impulse testing has great practical importance.

Present study aims at accurate identification of fault characteristics, viz. type, (series of shunt), nature (static or dynamic, if dynamic, its fault establishment time) and location of insulation failure, which may arise during impulse testing of transformer using temporal nature of acquired winding current. During actual impulse testing on real life transformer, depending on the condition of involved insulation, the insulation failure may occur with different values of fault establishment time.

Hence, to develop a fault pattern identification algorithm, known insulation failures are emulated in analog model of 33 kV winding of 3 MVA power transformer, having disc type winding of circular cross-section. For this fault emulation, analog series and shunt fault emulators have been designed and developed with different fault establishment times. After carefully studying the temporal natures of winding current due to series insulation failures, four different series fault emulators are designed with fault establishment times of zero (static), 600 ns, 900 ns and 1200 ns, respectively, to emulate the condition of involved disc-to-disc insulation in analog model. Similarly, four different shunt fault emulators with fault establishment times of zero (static), 300 ns, 400 ns
and 500 ns, respectively, are chosen to emulate the condition of shunt insulation of transformer.

By emulating insulation failures at various locations in the analog model of 33 kV winding of 3 MVA transformer, the winding currents resulting from impulse excitation have been acquired following tank current method. For impulse fault characteristics identification these acquired winding currents are processed by Cross-correlation (CCL) and Cross-wavelet transform (XWT). In the present study, the acquired winding currents of healthy (no-fault) as well as faulted winding insulation are correlated. From CCL and XWT spectra, sufficient numbers of features are extracted for localization and classification of insulation failures. It was possible to identify major insulation failure from these features without further processing. But, to improve impulse fault identification accuracy, i.e., to identify small breakdown (disc-to-disc failures) with good accuracy, computer aided algorithms, viz. Fuzzy c-Means (FCM), Bacterial Foraging (BFOA) and Wavelet Network (WN), are used as classifiers. The codes for classifiers have been written by the author and are implemented in C language and were executed in Windows platform.

The developed schemes have successfully classified the static and dynamic insulation failures within ±4% of the winding length. The XWT aided wavelet network based classifier has successfully identified and localized simultaneously occurring disc-to-disc insulation failures within ±9% of winding length. It has also been found that, irrespective of the classifier, the extracted XWT features have given higher impulse fault identification accuracy than the CCL or Discrete Wavelet Transform (DWT) features.

To the best of knowledge of the author, the following are original contributions of the present work:

- Design and development of dynamic fault emulators.
- Acquisition of winding current resulting from impulse excitation by emulating dynamic insulation failure with different fault establishment time at different winding locations in the analog model of transformer.
• Emulation of simultaneous dynamic disc-to-disc insulation failures with various fault characteristics at different winding locations in the analog model of a power transformer.

• Development of cross-correlation features aided clustering algorithm for classification of characteristics of impulse insulation failure.

• Development of cross-correlation features aided multi-dimensional wavelet network for accurate identification of impulse fault characteristics.

• Development of cross-wavelet transform aided bacterial foraging algorithm for accurate identification and localization of impulse insulation failure.

• Development of a novel scheme based on multi-dimensional wavelet network for pattern classification of simultaneously occurring disc-to-disc insulation failures in power transformer using features extracted by cross-wavelet transform.