CHAPTER 7

CONCLUSION

7.1 SUMMARY

The transformers are exposed to various disturbances such as electrical faults and mechanical defects. Electrical faults are mostly a consequence of insulation failure. These faults should be detected at an early stage with precision to prevent the transformer from damaging due to the propagation of these faults. SFRA is widely acknowledged as the best methodology for assessing the mechanical integrity of transformer winding. The application of statistical indicators and training of ANN classifier using the obtained frequency responses is considered to be complex and time consuming to determine the location of fault. Hence, a more generalised and simplified methodology is essential to detect and locate the faults. The proposed methodology of employing the hyperbolic model using the identified diagnostic parameter is checked and validated to determine the location of faults on different types of transformer windings using both measurement and simulation.

7.2 CONCLUDING REMARKS

The results are summarised based on the topics of the thesis.

- Sweep Frequency Response Analysis

The FRA test types, types of faults, various influencing factors affecting FRA measurements and the effect of variation in winding parameters on FRA signatures are discussed.
Inter disc faults in continuous disc winding

A simple algorithm with a new diagnostic parameter is developed for the identification of location of inter disc fault in a 22 kV continuous disc winding using SFRA.

- The percentage of fault is determined from the reduction in impedance at 0.1 Hz where, stray capacitive and skin effects are negligible.

- The change in the impedance at $f_{th1}$ for various faults, in terms of the defined Fault Factor is used to locate the faults with respect to the center of the winding.

- The percentage faults upto $(1/N)*100$, where N is the number of discs, can be located using the proposed methodology.

- To locate, whether the fault has occurred in the upper or lower sections of the winding, two methods namely $SFR_{50%}$ and ground capacitive current methods are proposed.

  - The methodology is employed for onsite transformer winding if the access to the centre tapping is available using $SFR_{50%}$.

  - Under the situations, where the access to mid point of the windings is difficult, the location of fault can be identified using ground capacitive current analysis.
Mathematical model for FF characteristics

A hyperbolic model is proposed to predict the fault factor characteristics and to locate the inter disc fault by measurement using a 22 kV continuous disc winding.

- As the FF characteristics are hyperbolic in nature, the proposed methodology employs the hyperbolic model, requiring only two terminal measurements to predict the exact fault location for different percentage of faults. The maximum percentage error for different percentage of faults is less than 1.4%.

- The values of the hyperbolic parameters are interpolated to predict the location for other percentage of faults.

- The proposed model is also checked for different percentage of faults in the intermediate sections with the percentage error less than 2.2%, thus validating the developed methodology to predict the occurrence of any percentage of faults at any location along the winding.

The methodology is validated for different types (continuous disc, interleaved and layer windings) and ratings (3.3 kV to 22 kV) of transformer windings.

SFRA using electrical equivalent circuit

The developed algorithm using hyperbolic model is validated by simulation using a 22 kV continuous disc winding.

- As the methodology requires the impedance characteristics only up to the first resonant frequency for the location of faults with
SFR<sub>50%</sub> method, low frequency equivalent circuit model is used for simulation studies.

- The transformer designers can obtain the hyperbolic models for any percentage of faults using circuit simulation package with only the low frequency equivalent circuit model at the design stage itself which will be useful for locating the fault.

- Inter turn faults

  The developed methodology is extended to determine location of inter turn fault and verified using a continuous disc winding.

  - The percentage faults upto \((1/(n*N)) \times 100\) is located using the proposed methodology where, \(N\) is the number of discs and \(n\) is the number of turns/disc.

  - The value of FF shows linear reduction in value from Region A to B or vice versa in a disc monotonically, based on the connection scheme in the continuous disc winding.

  - The values of the hyperbolic parameters are interpolated to predict the FF characteristics using the hyperbolic model and thereby the location of any percentage of inter turn faults whether it has occurred either near to the tank or core is identified with good accuracy.

  - The developed algorithm is checked upto inter turn faults in a continuous disc winding. The percentage and location of fault are detected correctly using the measured SFR and SFR<sub>50%</sub> of the healthy and faulty winding.
A simple and generalized methodology is developed to locate up to inter turn faults in any type of transformer winding.

7.3 SCOPE FOR FUTURE WORK

Based on work carried out in this research, the following areas have been identified for future investigations:

- Enhancement of the developed methodology to incorporate the effect of the aging of the insulation.

- Investigation of the methodology in the windings of the electrical machines such as induction motors.

- Extension of the algorithm to detect the location and occurrence of the faults at multiple locations along the winding.