CHAPTER 7

CONCLUSION

The bias voltage test recommended by IEC as a method of testing of the longitudinal insulation of high voltage switchgear permits to test the longitudinal insulation as per conditions that actually occur in power systems. This method of testing demands an expensive test circuit. However the performance of the equipments can be guaranteed better with bias test procedure as compared to the equivalent one terminal test procedure. It permits to optimise the dimensions of the equipments for a given voltage stresses. For switchgear of very high rated voltages it is an important consideration that the phase-to-ground insulation of the test object need not be increased beyond the normal value for testing of the longitudinal insulation. The standards have not given test circuit for conducting bias voltage tests. The bias voltage test circuit requires many additional equipments as compared to the equivalent one terminal test circuit. Protection is required for the test transformer insulation when flashover occurs across the longitudinal insulation. Damping resistor is used in series with the high voltage terminal and sphere gap is connected across the transformer terminals for the protection of winding insulation from high transient overvoltages. Location of the high voltage damping resistor is most important in the bias test circuit. Different locations of damping resistor, legally meets the requirement of the standards but do not satisfy the systems requirements.

IEC publications 56 and 129 have specified some of the requirement to be satisfied while conducting the bias voltage test on longitudinal insulation. However, the same can be interpreted in different ways depending on ones conveniency. These standards have also specified the impulse voltage and AC bias voltage levels to be applied to the test object but it is not clearly stated how the atmospheric correction factors should be applied to both the test voltages. All these aspects have been studied at depth, and the summary of work done and concluding remarks are given in this chapter.

7.1 Review of the work done and conclusions:

The objectives of the present thesis as mentioned in Chapter 1 is to study:

a) the different bias test circuits from the point of view systems requirements and suggest the one which gives the reliable performance of the equipments when tested for bias withstand voltage test.

b) how best the winding insulation of the high voltage testing transformers can be protected from the transient overvoltages during bias voltage test, and

c) to propose a suitable humidity correction factor for bias voltages.

IEC publications 56 and 129 allow to conduct either equivalent test (i.e.sum of the two voltages is applied to one terminal the opposite being grounded) or bias voltage test on the longitudinal insulation. The equivalent test is performed by overinsulating the base in order to prevent flashover to earth. The disadvantage of this method is that over insulation changes the field configuration across the open gap, and consequently, the breakdown strength of the open gap under these circumstances may be different from that under normal service conditions. While conducting bias voltage test, the AC power frequency voltage is applied to one terminal and impulse voltage is applied to the other terminal, the peak of the impulse being synchronised with the AC voltage peak having a polarity opposite to that of the applied impulse. For conducting bias voltage test it is not necessary to raise the ground insulation beyond the normal value because the impulse voltage applied to the impulse terminal of the test object is either equal to or less than the phase-to-ground withstand level. Hence, the exact site conditions can be simulated at the laboratory and the performance of the equipment can be guaranteed better

For conducting bias voltage test, many additional equipments are required to meet the requirements of the standards and for the protection of the testing transformer in case flashover occurs accross the test object open gap. Such protection can be conveniently provided by:

- connecting a high voltage damping resistor
- connecting a sphere gap in parallel with the supporting capacitance.

Connection of a high voltage damping resistor in the bias test circuit is of prime importance. As discussed in chapter-3, it is concluded that from the protection point of view of the testing transformer the best location of the damping resistor is to connect it between the terminals of the test object and supporting capacitance. However, from the results reported in chapters 4 and 5, it is seen that such circuit configuration do not satisfy the systems requirement. Also, the longitudinal insulation do not get stressed to the required voltage stresses when high voltage damping resistor is connected between the terminals of the test object and the supporting capacitance. From the power systems requirement point of view and testing purpose, it is a must that the supporting capacitance should be connected directly at the AC terminal of the test object. Otherwise, the voltage distribution across the test object is affected and hence the reliability of the performance of the equipments can not be ensured when installed in the power systems.

Further, standards do not give atmospheric correction factors especially for correcting bias voltages. Experiments were carried out at naturally occuring humidity between 2.0 $gm.m^{-3}$ to 18.0$gm.m^{-3}$. It has been observed that the present correction factors are not sufficient for correcting the bias voltages. The present correction factors are low for absolute humidity less than 11$gm.m^{-3}$ and high for absolute humidity more than 11$gm.m^{-3}$. If the longitudinal insulation is tested when absolute humidity is very high, say greater than 20gm.$\bar{m}^3$, i.e. preferably during summer in tropical countries then the longitudinal insulation may withstand higher voltages, if corrected as per present correction approach of IEC publication-60. However, if the same equipment is tested when absolute humidity is very low, say 2gm.$\bar{m}^3$, then it may so happen that the equipment which has passed the test when it was tested at higher humidity may not pass the test when the humidity is low.

The following are the important contributions made in this thesis.

1. The correct bias test circuit, which satisfies the requirement of power systems is established. To ensure the correct performance of the switchgear when installed in a power system, the high voltage damping resistor must be connected between the terminals of the supporting capacitance and the test transformer while conducting dielectric tests in the laboratory. This circuit arrangement will stress the test object to the required test voltages.

2. It is a must to use damped capacitive voltage divider for the accurate measurement of the voltage distortion on the AC wave. The capacitive voltage divider without damping gives erroneous results.

3. It is a must that the supporting capacitance should be connected directly at the AC terminal of the test object (refer Figure 4.2). This circuit arrangement may not give sufficient protection to the test transformer when flash-over occurs. The circuit time constant should be

increased to reduce the severity of the chopped wave. This can be done by connecting an additional load capacitance across the test transformer terminals. This capacitance will help to reduce the severity of the chopped wave. Experiments were conducted and it has been proved that this additional load capacitance does not affect the withstand capability of the longitudinal insulation.

4. It is very difficult to measure the lightning impulse transferred voltage U_A accurately for capacitive controlled rod-rod gap. When damped capacitive voltage divider having an internally connected damping resistor is used for the measurement of voltage U_A the magnitude of voltage U_A is found to be equal to the share of the voltage between test object capacitance and the divider capacitance. The supporting capacitance C_2 does not play any role for sharing of the lighting impulse voltage (refer figure 4.1). This phenomena may be attributed to the different time constants of the circuit elements.

5. The supporting capacitance required while conducting bias voltage test on rod-rod gap would be in the range of few hundreds of picofarads. However, for capacitive controlled rod-rod gap the required value of the supporting capacitance would be of the order of few nanofarads. The severity of the chopped wave is a function of supporting capacitance. For a given value of the short circuit impedance of the testing transformer, the transient frequency will be low for higher value of the supporting

capacitance and the transient frequency will be high for lower value of the supporting capacitance. Higher value of transient frequency does not lead to generation of high transient over voltages.

6. For capacitive controlled rod-rod gap the 50% lightning impulse discharge voltage U_{50} increases with the increase in damping resistance when connected between the terminals of the test object and supporting capacitance. The percentage increase of U_{50} is as high as 23% when damping resistance of 8.56 Kilo-ohms is connected. The increase in U_{50} value is not linear with the increase in damping resistance.

7. U_{50} switching impulse voltage also increases with the increase in damping resistance for capacitive controlled rod-rod gap. The increase in U_{50} is approximately 10% when damping resistance of 8.56 Kilo-ohms is connected between the terminals of the test object and the supporting capacitance.

8. For rod-rod gap, U_{50} lightning impulse voltage increases linearly with the increase in damping resistance. The percentage increase in U_{50} is maximum 0.7% when damping resistance of 8.56 Kilo-ohms is connected between the terminals of the test object and the supporting capacitance. This is negligible as compared to the capacitive controlled rod-rod gap. Thus, while conducting bias voltage test on the longitudinal insulation of rod-rod gap the damping resistor may be connected between the terminals

of the test object and the supporting capacitance, so that the severity of the chopped wave reduces.

9. The measured values of U_{50} for capacitive controlled rod-rod gap are approximately 4.5% more as compared to the calculated U_{50} for both lightning and switching impulse voltages. This is attributed to the different electrode field configurations because of change in circuit connections.

10. While conducting bias voltage test on circuit breakers (C_1=600 pF and C_2=13200 pF) when a damping resistor of 8.56 kilo-ohms is connected between the terminals of the test object and the supporting capacitor, the longitudinal insulation of the circuit breaker will be stressed less by approximately 20.4% of the lightning impulse voltage and 1% of the power frequency voltage (this is because of compensation error) while conducting lightning impulse bias test, and will be stressed less by approximately 10% of the switching impulse voltage while conducting switching impulse bias test.

11. While conducting bias voltage test on rod-rod gap when a damping resistor of 8.56 kilo-ohms is connected between the terminals of the test object and supporting capacitance C_2(C_2=866.6pF), the longitudinal insulation will be stressed less by approximately 0.65% of the lightning impulse voltage and 0.21% of the power frequency voltage while conducting lightning impulse bias test, and will be stressed less by approximately 2.3% of the

switching impulse voltage while conducting switching impulse bias test.

12. The present humidity corrections specified by IEC publication-60 are not sufficient for bias voltages. For example, the error in humidity correction factor, when absolute humidity is $2gm.\bar{m}^3$ is of the order of -3.21% and at $18gm.\bar{m}^3$ humidity the error is of the order of 2.8%. This is too large and can not be neglected.

13. A new correction approach is recommended for humidity correction factor under bias voltages. The value of exponent "W" for an open gap clearance of 1500 mm is found to be 1.2 for both rod-rod and sphere-rod gap electrode congiguration

14. During positive switching impulse bias test the AC corona produced at the power frequency terminal enhance the voltage withstand capability of the open gap insulation system.

15. The humidity correction factors specified by IEC publication-60 for positive polarity switching impulse voltage is not sufficient (even for phase-to-ground insulation).

16. The 50% bias flashover voltages, when expressed as a function of the time-to-crest exhibits the famous U curve relationship. The critical time-to-crest for rod-rod gap under bias voltage is evaluated to be about 58 X D μs,

where D is gap spacing in meters.

17. The 50% discharge voltage $(U^{+}_{SI} + U^{-}_{AC})_{50}$ decreases by approximately 3.5% when time shift between the two peaks is +5ms., and peak value of voltage U^{-}_{AC} is not varied. This reduction in the gap strength is too low as compared to the reduction in the gap strength observed while testing phase-to-phase insulation system. However, the voltage $(U^{+}_{SI} + U^{-}_{AC})_{50}$ decreases by approximately 15.5% when time shift between two peaks is +3ms. and the peak magnitude of voltage U^{-}_{AC} is maintained same by increasing voltage U^{-}_{AC}. This reduction is because of the space charge effect.

18. Air density corrected 50% bias flashover voltages are same under wet and dry test conditions. When humidity correction factor is applied to the dry flashover voltages then the dry flashover voltages are higher by 8 to 10% as compared to the wet 50% flashover voltages.

7.2 Suggestions for further work.

As reported in chapter no.6, the tests were performed only with positive polarity switching impulses to study the effect of humidity on bias flashover voltages. To reduce the complexity of analysis only one waveshape was chosen. (240/2500 μs standard switching impulse wave according to IEC publication-60). Further work on this subject can be conducted on the following topics:

1. Humidity correction factors for positive and negative lightning impulse bias voltages.

2. Humidity correction factor for negative polarity switching impulse bias voltages.

3. Influence of humidity on critical time-to-crest under bias voltages.

4. Influence of rain on lightning impulse bias flashover voltages.

5. Influence of voltage distortion on AC wave on voltage withstand capability of the longitudinal insulation under bias voltages.