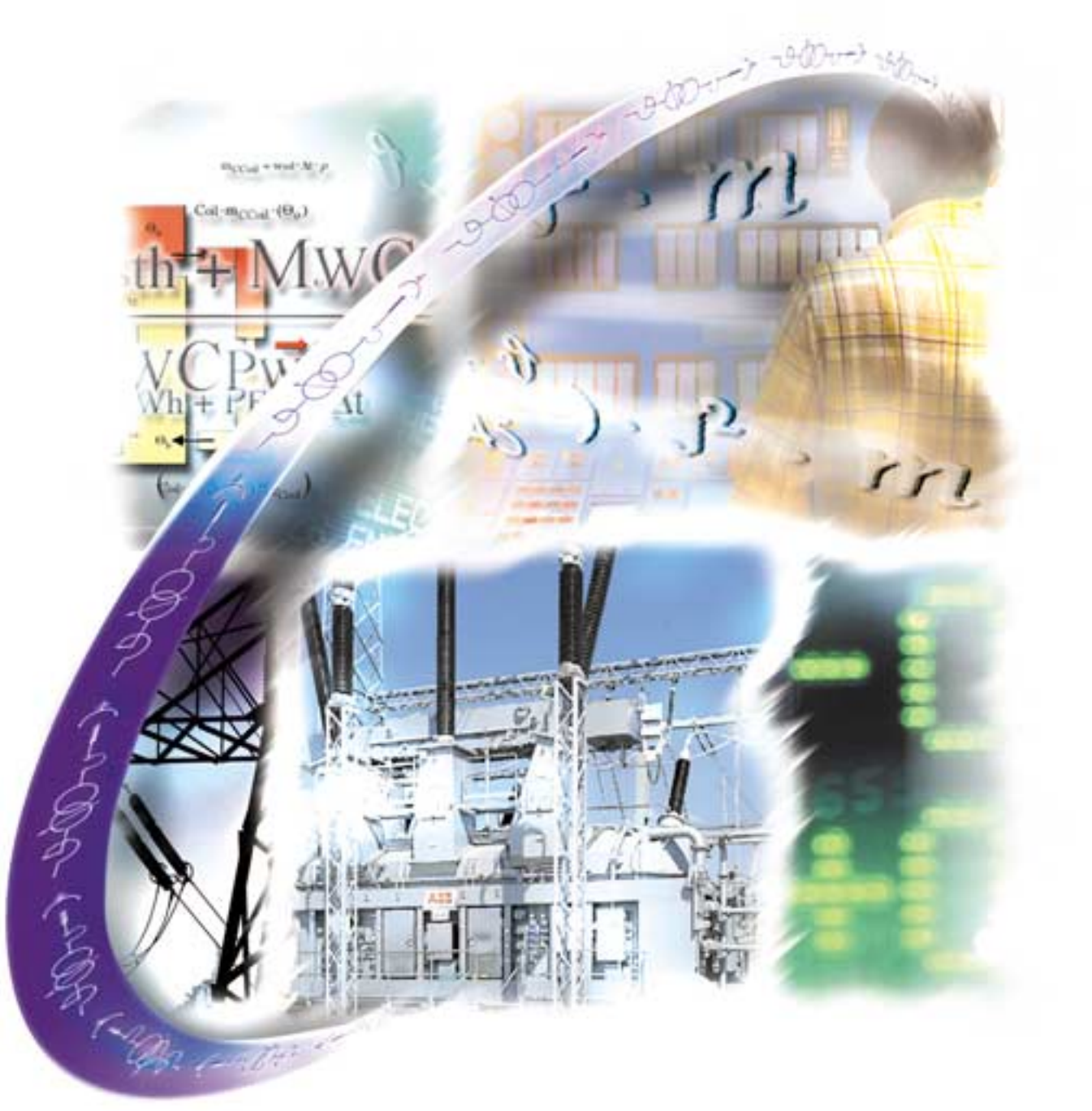
Testing of Power Transformers

Routine tests, Type tests and Special tests



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under participation of

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Preface

Remember school days? Nothing caused more excitement than the teachers' announcement of a test. Because a test confirms what you know, if you can apply in real life what you have learned in a classroom, under strict, rigorous and controlled conditions. It is a chance to demonstrate excellence.
Testing of power transformers seems like a similar experience; and therefore ABB undertook to write this book.

Transformer testing has developed considerably over the past years. It evolved from the simple go-no-go verdict into a sophisticated segment within transformer manufacturing. In this book we have laid down important aspects on transformer testing in order to enhance the understanding of the testing procedures and its outcome.

The book represents the collective wisdom of over 100 years of testing power transformers. It has been written for transformer designers, test field engineers, inspectors, consultants, academics and those involved in product quality.

ABB believes that the knowledge contained in this book will serve to ensure that you receive the best power transformer possible. The more knowledgeable you are, the better the decisions you will take.

Zürich, October 2003

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Explanation to the vocabulary

The authors vocabulary in the test book is based on IEC Standards. There are no really important differences between the vocabulary applied in IEC and IEEE (ANSI) Standards.
The only exception is the use of the words „earth"/"earthed" (according to IEC) and „ground"/"grounded" (according to IEEE).

Testing of Power Transformers

1. Introduction

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1.1 Why transformer testing?

Tests serve as an indication of the extent to which a transformer is able to comply with a customer's specified requirements; for example:

- Loading capability
- Dielectric withstand
- Further operating characteristics

Tests are also part of a manufacturer's internal quality assurance program. A manufacturer's own criteria have to be fulfilled in addition to requirements specified by customers and applicable standards.

Differing requirements are generally combined and published in national and international standards. The primary Standards Organizations are IEC and ANSI. These standards are often used directly to develop national standards. IEC is the abbreviation for International Electro-technical Commission and ANSI stands for American National Standard Institute, Inc.

In the electric area, ANSI has to a great extent delegated the writing and publication of standards to IEEE, the Institute of electric and Electronics Engineers, Inc.

The IEC and IEEE Standards specify the respective tests that verify compliance with the above requirements; e.g.:

Temperature rise tests to verify loading capability, see section 11

Dielectric tests to demonstrate the integrity of the transformer when subjected to dielectric stresses and possible over-voltages during normal operation, see section 2.

No-load and load loss measurements, short-circuit impedance measurements, etc. to verify other operating characteristics.

1.2 Types of tests

The IEC 60076-1 [1] and IEEE Std C57.12.00 [50] Standards distinguish between the following types of tests:

- Routine tests
- Type- or design[1] tests
- Special- or other[1] tests

Routine tests

Routine tests are tests required for each individual transformer.

Typical examples:
Resistance measurements, voltage ratio, loss measurements, etc.

Type- or design tests

Type or design[1] tests are conducted on a transformer which is representative[2] of other transformers, to demonstrate that these transformers comply with specified requirements not covered by routine tests.

Typical example:
Temperature rise test.

Special- or other tests

Special- or other[1] tests are tests other than type- or routine tests agreed to by the manufacturer and the purchaser.

Typical example:
Measurement of zero-sequence impedance, sound level measurement, etc.

[1] *Term used in the IEEE Standards [50], [51]*

[2] *"Representative" means identical in rating and construction, but transformers with minor deviations in rating and other characteristics may also be considered to be representative [1].*

Note:

Depending on the respective standard and the maximum system voltage, certain dielectric tests, such as lightning impulse tests, for example, may either be routine tests, type tests or special tests, (see section 2, table 1 and 2). The same is true for switching impulse tests.

1.3 Test sequence

As the Standards do not lay down the complete test sequence in an obligatory basis, it is often the source of long discussions between customer and manufacturer.

On the other hand the test sequence for dielectric tests is generally fixed in IEC and IEEE Standards.

Following all existing standard regulations and recommendations concerning this matter followed by recommendations of the authors, see section 1.3.3.

1.3.1 IEC Standards

IEC 60076-3 (2000) [3], clause 7.3

“The dielectric tests shall, where applicable and not otherwise agreed upon, be performed in the sequence as given below:

- Switching impulse test
- Lightning impulse test (line terminals)
- Lightning impulse test (neutral terminal)
- Separate source AC withstand test (Applied voltage test)
- Short-duration induced AC withstand voltage test including partial discharge measurement
- Long-duration induced AC voltage test including partial discharge measurement”

This test sequence is in principle obligatory; but allows other agreements between customer and manufacturer.

IEC 60076-1 (2000) [1], clause 10.5

“In deciding the place of the no-load test in the complete test sequence, it should be borne in mind that no-load measurements performed before impulse tests and/or temperature rise tests are, in general, representative of the average loss level over long time in service. Measurements after other tests sometimes show higher values caused by spitting between laminate edges during impulse test, etc. Such measurements may be less representative of losses in service”.

This test sequence is a recommendation and not obligatory.

1.3.2 IEEE Standards

IEEE Std C57.12.90 [51], clause 4.3

“To minimize potential damage to the transformer during testing, the resistance, polarity, phase relation, ratio, no-load loss and excitation current, impedance, and load loss test (and temperature-rise tests, when applicable) should precede dielectric tests. Using this sequence, the beginning tests involve voltages and currents, which are usually reduced as compared to rated values, thus tending to minimize damaging effects to the transformer.”

Also this test sequence is recommendation and not obligatory.

IEEE Std C57.12.90 [51], clause 10.1.5.1

“Lightning impulse voltage tests, when required, shall precede the low-frequency tests. Switching impulse voltage tests, when required, shall also precede the low-frequency tests.

For class II power transformers, the final dielectric test to be performed shall be the induced voltage test.”

This test sequence is obligatory.

1.3.3 Recommendation of the authors

Taking into account all IEC- and IEEE regulations and recommendations and based on their own experience the authors propose the following test sequence:

- Ratio, polarity and phase displacement
- Resistance measurement
- No-load test (followed, if specified, by the sound level test)
- Load loss and impedance
- Zero-sequence impedance test (if specified)
- Dielectric tests:
  - Switching impulse (when required)
  - Lightning impulse test (when required)
  - Separate source AC voltage test
  - Induced voltage test including partial discharge test.

The test sequence of the tests preceding the dielectric test can be slightly changed due to test field loading or other operational reasons.

1.4 Remarks concerning this test book

This test book has an initial chapter covering dielectric integrity in general (section 2), since verification of dielectric integrity is the result of different types of successful dielectric tests. The first chapter is then followed by descriptions of each individual test.

The individual tests and measurements are covered in greater detail in the following sections (sections 3 to 18):

- Measurement of winding resistance (R), section 3.
- Measurement of voltage ratio and vector group (phase displacement) (R), section 4.
- Measurement of impedances and load losses (R), section 5.
- Measurement of no-load loss and no-load current (R), section 6.
- Separate source AC withstand voltage test (R), section 7.
- Induced voltage test (R alternatively also S), section 8.
- Partial discharge test (R alternatively also S), section 9.
- Impulse test (R and T), section 10.
- Temperature rise test (T), section 11.

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- Measurement of zero-sequence impedances (S), section 12.
- Short circuit withstand test (S), section 13.
- Sound level measurement (S), section 14.
- Test on on-load tap-changers and dielectric tests on auxiliary equipment (R), section 15.
- Measurements of the harmonics of the no-load current (S), section 16.
- Measurement of insulation resistance (S), section 17.
- Measurement of the dissipation factor (tan δ) of the insulation capacitances or insulation power-factor tests (S), section 18.

Note:

R = Routine test

T = Type test

S = Special test

The individual test items may be interwoven and carried out as part of a combined average to verify certain characteristics, such as resistance measurement.

Several aspects have been considered regarding the tests and test procedures, such as:

- Purpose of the test and what is to be achieved by a specific test.
- Means of generating the supply voltage and current for the test.
- Means to measure or indicate the test object response.
- Means to verify the integrity of the test object.
- Means to verify presence or absence of damage caused by a specific test.

Symbols and abbreviations in this test book follow present IEC Standards where applicable.