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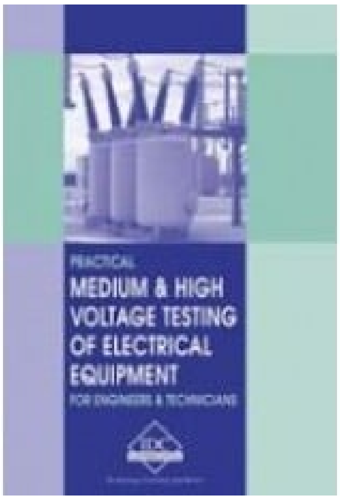
TH-E - Practical Medium & High Voltage Testing of Electrical Equipment for Engineers and Technicians



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This manual is designed to familiarise you with various aspects of testing general electrical equipment and high voltage testing in particular. Examples are cited from various international standards regarding the procedure for conducting of tests and interpreting the test results. The need for keeping proper records of tests conducted both in the initial stages and later during routine maintenance is discussed. Some of the tests are too complex to be performed on a routine basis or may require specialised equipment which may not be normally available to user industries or even manufacturers. This is where the services of an independent and accredited test lab is useful. The role of such labs is briefly discussed.

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First Chapter

An Introduction to Practical Medium & High Voltage Testing of Electrical Equipment for Engineers and Technicians

1 Introduction

1.1 Electrical system

The electrical distribution network has become the main nerve center of economic activities today. When electricity was invented a couple of centuries back, no one could have imagined the quantum of electricity being generated in the world today; it runs to millions of mega watts. This had been possible by the simultaneous invention of many electrical equipment which are used to distribute the generated power to many remote corners of the world.

The following is a very simple network of an electrical system comprising of many electrical equipment, shown in single line diagram.

Figure 1.1

Typical HV/MV electrical network

1.2 HV AND MV equipment

The above diagram includes transformers which are mainly used to transform the voltage from one value to another. Hence it is obvious that any electrical system intended to serve many consumers, whether in a plant or a township or a country, primarily consists of equipment whose voltage ratings will differ from one zone to another. This is mainly because of the use of transformers, which are the backbones of efficient electrical distribution at minimum losses.

The use of equipment at different voltage levels has led to the need for demarcation of type of equipment based on their normal operating voltage. This is termed as Nominal operating voltage of equipment. The main reason for demarcation is to limit the cost of equipment to be used at a particular voltage. It is some times very common to find equipment rated at say 6.6 kV and 13.8 kV being used at 3.3 kV and 11 kV respectively. But the reasons may be more due to the range manufactured in a country from where the particular equipment is imported.

The operating voltages are broadly divided to three main categories:

- High Voltage refers to voltages above 69 kV as per ANSI standards. It is also common practice to refer to this range as Extra High Voltage (EHV) in Europe and Asian countries.
- Medium Voltage (MV) refers to equipment above 1 kV up to and including 69 kV. In some parts of the world, MV voltage is used for capacity up to 3.3 kV, beyond which the term HV is applied. (That is one reason for the term EHV)
- Low Voltage (LV) refers to voltages up to 1 kV but generally the operating voltage seldom is expected to be between 500 to 1000 V under this category.

Low voltage distribution is the most common one ranging from the simple lighting switch where you are reading this manual to small switch boards and motor control centers. LV equipment are mainly limited for controlling small power loads whose ratings may range from fractional to a few hundreds of HP.

The equipment considered in this manual mostly cover those falling in the EHV, HV and MV category with a brief description covering LV equipment as well. It shall be remembered that most of the tests which verify the condition of equipment insulation do need test voltages exceeding 1 kV but at the same time the testing and measurements invariably derive these high voltages using low voltage equipment.

1.3 Use of HV and MV equipment

Though there is no theoretical boundary or battery limits for the areas using HV and MV equipment but practical reasons dictate the use of HV and MV equipment based on the power requirements and applications.

1.3.1 High voltage equipment

HV equipment is extensively used in the following areas.

- Generating stations where the bulk of the generated power is transferred at voltages above 110 kV up to and including 765 kV; mainly to cut down the transmission losses and the transmission cost.
- Intermediate substations of utilities involved in power transmission and distribution, which are mainly used to step down the very high voltages to a lesser high voltage to enable flexibility in the power distribution covering switching/changeover applications and for local distribution substations.
- Receiving substations in utilizing industries where the maximum receiving voltages are generally limited to a maximum of 275 kV with the minimum in the range of 110 to 132 kV. (Though majority of the industries i.e. almost 90% in terms of numbers, receive power at medium voltage from as low as 3 kV in some parts of the world).

1.3.2 Medium voltage equipment

The use of MV equipment is mainly applicable in the following areas.

- Industries whose plant demand is limited to around 50 MVA. However the provision of MV voltage is more governed by the availability of grid lines in the vicinity. (There are no strict common rules in international standards regarding the limitation of use of medium voltage with respect to MVA demand but almost followed strictly due to practical reasons).
- Receiving substations in commercial buildings and residential townships/apartments, where the incoming voltages are mostly limited to around 13.8 kV.
- Generating stations. Since the generating voltage is limited to around 33 kV, it is necessary to use MV equipment matching the generated voltage before transferring the power through the local grid at High Voltage.
- Induction and synchronous motors of many industries and commercial complexes with their terminal voltages invariably limited to ratings of around 3 kV to 6.6 kV for less than 5 MW and upto 13.8 kV beyond these ratings. However motors with voltages in the range of 69 kV are already produced under special applications and this has been possible with developments in designs leading to easy availability of insulated cables rated for these higher voltages.

1.3.3 Common HV and MV equipment

The common HV and MV equipment used in the electrical system are generally the following:

- Circuit Breakers (HV and MV)
- Air break switches/disconnectors/ isolators (HV and MV)
- Instrument transformers (CTs, PTs, etc, HV and MV)
- Switchgear panels (limited to MV)
- Transformers (HV and MV)
- Lightning arrestors (HV and MV)
- Generators (MV)
- Induction and Synchronous Motors (MV)
- Bus ducts (MV)
- Capacitors (MV)
- Cables (HV and MV)

It is to be noted almost all the above equipment are also available for low voltage use. This manual will cover electrical testing procedures adopted for a majority of the above equipment including their main insulating mediums like oil, SF6, etc.

1.4 Need for testing

The continuity of power distribution depends on the reliability of the electrical equipment in a system. While the reliability of many equipment have increased manifold during the last century, it is not recommended to connect any finished equipment to a system directly from the manufacturing place, unless its performance is proven. Earlier manufacturers had to think of many ways to prove the worthiness and reliability of their equipment. Nevertheless due to various reasons, manufacturers duplicating proven equipment also gained entry into the market. This had led to claims and counterclaims by the sellers, with consumers and end users being confused.

However the concepts have changed and bringing equipment under a common umbrella to prove their performance have slowly become the practice in every country. Each country had established committees and organizations to ensure the uniformity and performance of electrical equipment in an orderly way. This has led to the release of electrical standards in each country (for all electrical equipment). The major content of most of these cover the minimum tests that are to be conducted on any equipment in an environment that may be more severe than normal operating conditions; in terms of voltage and current levels.

With the sharing of knowledge among intellectuals from different regions and with globalization leading to the use of electrical equipment from different parts of the world, a common way to establish the capability of equipment has been accepted. This has lead to mandatory testing of electrical equipment before being put into use. The tests and the methods to be followed are covered in all electrical standards.

It can be concluded that testing on electrical equipment is needed

- To prove the performance of an equipment before being put into service
- To ensure that the equipment is assessed on a common basis with respect to their technical capabilities
- The end user is confident about the capability and performance of the equipment where it is to be used
- An assurance is established to show that the equipment will not cause any damage to property and personnel, when the equipment is put into service.

1.5 Purpose of testing

Most electrical equipments are produced by assembling various components made of different materials. The internal construction of the final equipment like transformers, circuit breakers, etc are not visible from the outside and it is not possible to visually check the performance of each and every part under a particular operating condition. Hence it is necessary to find ways to check the performance of the equipment in its full form without dismantling it. Accordingly ways and means have been drawn out to check the performance of the complete equipment in its final form which has become the basis of all electrical equipment standards. The testing helps in identifying the defects that may be inherent in particular equipment. Hence it enables the user to take a decision whether to use or not to use the equipment under known circumstances.

The purpose of electrical testing on major equipment is basically to ensure that the equipment will function as desired, when it is installed and energized within its specified voltage and load conditions. This is basically like an insurance premium to be spent before the equipment is accepted in a particular installation. The other purpose is to develop a set of base line test results of the equipment that can be compared in future to identify deterioration and therefore for taking corrective actions.

1.6 Categories of tests

Depending on the area/nature of the tests, they may be categorized as

- Factory tests
- Field/pre-commissioning tests

The factory tests are the major tests that are to be conducted by the manufacturer before declaring that the equipment suits a particular application.

These are categorized as:

- Type tests/design tests: These are normally done on identical equipment. These tests can be destructive in some cases in a sense that the type tested equipment may not be usable again. Hence it is not expected that the equipment under use is type tested but its design should have been proven by conducting tests on similarly designed equipment. All type tests are not destructive. Some times when multiple quantities of similar equipment are ordered, it is acceptable that one unit alone passes these tests.
- Routine tests: These are the necessary basic tests that are to be conducted by a manufacturer even if a customer does not specifically indicate this requirement. Any equipment which had failed in any of the routine tests is generally NOT to be used for the desired application. However under exceptional cases some routine tests may be repeated after making minor alterations to internal construction. It may be noted that all electrical equipment in service, should pass the routine tests.
- Acceptance tests: Some of the tests are to be conducted in case the operating conditions demand the same. These tests may not be applicable for all operating conditions and are mostly guided by the application of the particular equipment.
- Sample tests: When tens and hundreds of identical equipment are ordered, it is not necessary to conduct the same set of tests on each and every unit. Standards define the quantities to be considered for sample testing and the items are randomly tested to prove their capacity. The quantities to be selected are defined by a table or by some formula and samples are chosen accordingly.
- Special tests/other tests: These are defined by standards for some specific equipment at some specific ratings/capacities. These are invariably defined for tests like partial discharge tests, impulse withstand voltage tests, etc which are normally applicable for operating voltages above specified ranges like 132 kV or 220 kV.
- Field tests: As the name implies these are tests that are conducted on equipment in the field of service before being put into service. Invariably most of the pre-commissioning tests are almost same as routine tests (like megger tests, insulation tests, etc).

- Maintenance tests: These are tests conducted at regular intervals as part of maintenance checks to maintain performance. Typical tests are conducted on items like relays, etc which control the HV equipment and on oil which is the insulating medium in transformers.

1.7 Variations to test voltages and results

It is not practically possible to test the electrical equipment in ambient conditions at which they are expected to be in service. The major conditions that can affect performance and its acceptance by the end user are

- Altitude above sea levels
- Maximum and minimum ambient temperatures
- Tolerances on test results

Hence it is customary to define the performance requirements at pre-defined altitude and temperature and also to correct the test results to some basic temperature conditions; so that the equipment performance can be evaluated in a true sense.

1.7.1 Altitudes above sea level

The major requirement for any electrical equipment is that it shall be able to withstand some minimum voltage across its terminals and also across each terminal to earth, since the equipment is expected to carry its rated voltage throughout its life. Hence almost all HV and MV equipment shall be tested to prove its capacity to withstand voltage conditions. These are generally called Dielectric tests. Most electrical equipment has its terminals separated by air. This means that air is the insulating medium, though internally their parts may be filled with some other insulating medium like oil. It is well known that the breakdown voltages across two terminals separated by air vary with the ambient temperature due to the presence of moisture at higher altitude conditions. Hence it is usual to define test voltages at some minimum altitude conditions. The standards normally consider an altitude of 1000 meters above sea level, to define the test voltages to be withstood by equipment. Correction factors shall be applied for altitudes above this value, which means the equipment, shall be able to withstand higher operating voltages at higher altitudes.

1.7.2 Temperature conditions

Similarly the operating temperature can vary the factors like impedance, temperature rise, etc. The variation of temperatures could be critical to assess the losses of major electrical equipment (like power transformers, motors, generators, etc). It is usual to correct the results to a common temperature, which is 75ºC for electrical equipment. Hence the testing engineer shall ensure that the test results are properly corrected to take care of the altitude and temperature conditions.

The operating temperatures can affect the ratings of some main equipment like transformers and generators because their current ratings are dependent on the windings that carry the currents. Hence it is necessary to define the ratings based on the expected operating temperatures.

1.7.3 Tolerances

The other major condition on which test results are dependant is the applicable tolerance level. It is necessary that there cannot be any tolerance on the test voltages after applying the above correction factors. This means that any equipment failing at 99.9 kV with its defined test voltage of 100 kV can not be considered to have passed this test. At the same time the losses and impedance values which are normally measured during tests, cannot meet the guaranteed figures exactly. Hence it is usual to define tolerances on test result values for such guaranteed figures and the equipment is accepted to meet the testing requirements if the results fall within the defined tolerance value.

The following sections also include the conditions and tolerances that are normally applicable for various HV/MV equipment test values and their respective results.